# NAVAL POSTGRADUATE SCHOOL

**MONTEREY, CALIFORNIA**

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## MBA PROFESSIONAL REPORT

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**An Analysis of**
**Earned Value Management Implementation**
**Within the F-22 System Program Office's**
**Software Development**

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**December 2006**


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**ABSTRACT (maximum 200 words)**

Department of Defense (DoD) use of Earned Value Management (EVM) program control tool has significantly increased in the last ten years. DoD acquisition policy and training promotes EVM as a cost and schedule management tool, tracking the earned value of the work completed per the baseline plan. Acquisition Category ID programs like the US Air Force F-22 fighter program use EVM to manage their software development efforts, but has the program's implementation of EVM followed the industry-recognized 32 criteria outlined in ANSI/EIA-748-A-1998 (Earned Value Management System Standards) necessary to successfully implement EVM?

Using these 32 criteria, an evaluation was performed, aimed at assessing the implementation of EVM in the F-22 program. The goal: to academically appraise the program's use of EVM in managing Spiral 2, an F-22 avionics software modernization effort. To accomplish this goal a detailed evaluation of how the program meets the 32 criteria was conducted along with analysis of program data, interviews of subject matter experts and a statistical questionnaire conducted with F-22 personnel. Results indicated areas of possible improvement in the use of EVM and potential changes to the F-22 development environment to improve planning, scheduling and budgeting of the EVM baseline.


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**AN ANALYSIS OF
EARNED VALUE MANAGEMENT IMPLEMENTATION
WITHIN THE F-22 SYSTEM PROGRAM OFFICE'S
SOFTWARE DEVELOPMENT**

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Submitted in partial fulfillment of the requirements for the degree of

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Major John C. Dibert

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Captain John C. Velez

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# EXECUTIVE SUMMARY

Department of Defense (DoD) use of Earned Value Management (EVM) program control tool has significantly increased in the last ten years. DoD acquisition policy and training promotes EVM as a cost and schedule management tool, tracking the earned value of the work completed per the baseline plan. Acquisition Category ID programs like the US Air Force F-22 fighter program use EVM to manage their software development efforts, but has the program's implementation of EVM followed the industry-recognized 32 criteria outlined in ANSI/EIA-748-A-1998 Earned Value Management System Standards and necessary to successfully implement EVM.

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The subjective evaluation of the 32 criteria exhibited several areas of interest. First, 22 of the 32 data points (68.75 percent) either met or exceeded the intent of their respective ANSI criterion by earning an *excellent* or *satisfactory* rating. Of the remaining data points, six (18.75 percent) exhibited either a *marginal* or *insufficient* rating, while four (12.50 percent) exhibited an *inconclusive* rating (an *inconclusive* rating resulted from insufficient supporting data). Major factors contributing to less-than-satisfactory ratings included usage of undefinitized contracts and an observed lag between cost data collection and reporting.

[1] Please refer to Chapters III and IV for a more detailed discussion of these findings.

The questionnaire, which reached 100 percent of government and contractor personnel dedicated to Spiral 2 (the first F-22 avionics software upgrade since Initial Operational Capability (IOC)), exhibited the following:

- Personnel had a slight majority opinion EVM has some value
- Personnel had a slight majority opinion EVM has some usefulness
- Most personnel are not aware of the ANSI/EIA-748-A-1998 EVMS 32 Criteria

Additional statistical analysis of the questionnaire concluded that:

- Higher EVM value resulted in more EVM usage
- Higher EVM usefulness resulted in more usage of EVM in managing
- Higher EVM knowledge did not result in higher EVM value

Finally, the interviews independently verified the separate assessment of the 32 criteria and served to explain the results of the questionnaire.

The summation of the 32 criteria evaluation, questionnaire analysis, and interviews led to the conclusion that the F-22 Program Team, with respect to its software development efforts, did meet the intent behind the industry standard ANSI/EIA-748-A-1998 with respect to most of the criteria. There were, however, several criteria that were found to be marginal or insufficient. Research identified several areas of incompatibility with regard to EVM and software development (or any other similarly dynamic environment) that may preclude functional managerial controls. Specifically, as software development efforts progress beyond early stages, less-defined tasks become more difficult to manage via EVM.

# I. INTRODUCTION

## A. BACKGROUND

### 1. Earned Value Management

DoD Program Managers' use of EVM as a measure of program cost and schedule performance has significantly increased in the last ten years. DoD acquisition policy and training promotes EVM as a tool for measuring program health by tracking the "earned value" of the work completed per the baseline plan.

Facilitating an intelligent discussion concerning EVM first requires a rudimentary knowledge of the EVMS as it exists today. Consequently, this paper offers the following primer for those either new to or requiring a refresher in the basics of EVM. Proposed methods for evaluating an EVMS and a discussion of the ANSI/EIA-748-A-1998 EVMS criteria follow the primer.

#### *a. An EVM Primer*

Earned Value Management: "…a tool for effectively integrating cost, schedule and technical performance management" (DAU, 2005). To integrate said cost, schedule, and performance involves making those measurements visible. The core of that visibility revolves around three measurements (DAU, 2005):

- **Budgeted Cost of Work Scheduled (BCWS) –** This measurement sums the budgets for all work scheduled for accomplishment—including in-process work—plus the amount of apportioned effort scheduled for accomplishment at a specified point in time. The BCWS value at project conclusion equates to *Budget at Completion* (BAC). Alternate terminology includes "planned value" and the *Performance Measurement Baseline* (PMB).

- **Budgeted Cost of Work Performed (BCWP)** – This measurement provides the value of work actually performed and uses budgeted costs to calculate the cost at a specific point in time. Also known as *Earned Value* (EV).

- **Actual Cost of Work Performed (ACWP) –** This measurement provides the costs actually incurred and recorded (as opposed to budgeted costs) in accomplishing the work performed at a specific point in time; normally the contracted organization provides ACWP data directly. Often it is simply called *Actual Cost* (AC).

Program Managers use comparisons of these three measurements to gauge a contractor's progress against an initially agreed-upon baseline (as a rule, the PMB). For instance, a quick comparison of BCWS and BCWP provides a useful measurement of Schedule Variance (SV).[2] An intuitive analysis reveals that when work performed exceeds work scheduled for a given program, the program in question is ahead of schedule.

Likewise, a quick comparison of BCWP and ACWP provides an equally useful measurement known as Cost Variance (CV).[3] At an elementary level, when actual costs exceed budgeted costs within a scrutinized program, that program warrants a "cost overrun" classification. Armed with CV and SV, a program manager and his or her Integrated Product Team (IPT) can now calculate a rudimentary Estimate at Completion (EAC).

For those not familiar with the term, EAC answers "What do we *now* expect the total job to cost?" (Haupt, 2002). Take an original EAC of 20 and a one time CV of -4. Subtract this 4 point overrun from the original EAC of 20 (i.e., 20 – (-4)), and the new EAC reflects a projected cost of 24. The basics of EAC now explained, the next level of analysis involves creating indices for both cost and performance measurements.

Within the EVM body of knowledge, these indices are known as *Cost* and *Schedule Performance Index* (CPI and SPI).[4] The CPI indicates cost performance

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2 SV = BCWP - BCWS

3 CV = BCWP - ACWP

4 CPI = BCWP / ACWP

efficiency related to work the contractor has actually accomplished at a specific point in time. In other words, it provides a measurement of the value of work the program receives from every dollar given towards the effort. For example, assume BCWP = 8 and ACWP = 10. The resulting CPI (.8) reports that every dollar invested into the project results in .80 cents of effort. CPI's ultimate use (assuming a constant CPI) stems from enabling government IPTs to project the final cost of a contract and even determine the likelihood that the contractor can recover (Heise, 1991, p. 95).

Along those same lines, SPI indicates schedule efficiency at a specified point in time. For example, if BCWP = BCWS, then SPI = 1. An index of 1 indicates that the supplier is performing on schedule whereas an index of 1.1 indicates an ahead-of-schedule condition (Smith, 1977). Like CPI, SPI's ultimate utility stems from bestowing the ability to project the final completion date of a contract alongside the probability that the contractor can meet or beat the original project completion date, given a reliable budget.

This segment represented a very basic working knowledge of EVM; the next topic concerns evaluating the effectiveness of EVM within a given program.

### *b. Evaluating the Effectiveness of an EVMS*

When, in 1995, the National Defense Industrial Association (NDIA) decided it was too unwieldy and expensive to abide by DoD's 35 Cost/Schedule Control Systems Criteria (C/SCSC), industry leaders took initiative and developed EVMS, which remains more or less in its same form today.[5] Little more than twenty months later, the 32 guidelines from the new industry standard, American National Standards Institute / Electronic Industries Association (ANSI/EIA) 748, became the DoD baseline for EVMS, as well. Essentially, ANSI/EIA-748-A-1998 states how to effectively apply earned value concepts that will aid in successful program management (Fleming & Koppelman, 2000). Even knowing that, one might ask, "So what?"

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SPI = BCWP / BCWS

To begin with, history has shown that no single EVMS can hope to meet every need (management, reporting, etc.) with respect to performance measurements. Differences in programs, as varied and unrelated as organizations, weapon system architecture—even how well government and contractor teams interact—make it unrealistic to prescribe a one-size-fits-all approach to cost and schedule controls (Johnson, 2006).

Instead, the EVMS Guidelines provide the basis for determining whether contractors' EVM systems meet standards. These broad guidelines serve a two-fold purpose (Scott, 2005). First, they allow for common sense applications (read: flexibility) on both sides of the table—government and contractor. Second, their comprehensive nature reassures the government that with each report it receives reasonably reliable performance data.

That first purpose leads to the conclusion that common sense should rule the design, employment, and subsequent iterations of a program’s EVMS. Unfortunately, many times government standard operating procedures and common sense have not positively correlated. More often than not, standard operating procedures meet the letter of the guidelines, but not their intent. Lacking support for intent, the resultant incongruence almost always eventually fails to support management's needs, and the EVMS inevitably fails as a management control system (Scott, 2005).

The second purpose depends heavily on one assumption in particular: the contractor possesses effective internal controls (Scott, 2005). The presence of these controls makes reliable reporting possible. Without that foundation, even the most stringent process attempting to follow ANSI/EIA-748-A-1998 fails proper implementation due to uncertainty surrounding the cost and schedule figures produced by the contractor.

EVM systems that comply with the intent and nature of the guidelines facilitate project work scoped in its entirety, to include detailed planning. Properly

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[5] Fleming and Koppelman assert that industry leaders perceived the previous DoD-driven standards as non-user-friendly and incompatible with the needs of private industry.

implemented EVM systems also facilitate full integration of cost, schedule, and project performance objectives into a performance measurement baseline against which actuals (work, cost) can be measured. An effective EVM system tailors itself to a given program based on a foundational baseline that fosters full and / or appropriate control.

From a reporting standpoint, an effective EVMS uses and provides information that utilizes the defense industry standard Work Breakdown Structure (WBS), which delineates product work packages as well as organizational responsibility. Within each WBS, quantifiable measurements of metrics—to include SV, CV, SPI, CPI, etc.—should generate at the lowest appropriate organizational levels where the actual work occurs. From those fundamental organizational levels up through the highest levels of management, the EVMS should reflect strong discipline in reporting. Otherwise, management "dashboards", or high-level reporting to upper management used for decision-making, would prove ineffective.

From a management utilization standpoint, an effective EVMS provides a virtually on-demand analysis of significant variances (e.g., SV, CV) along with narrations of forecasted impacts. An effective EVMS becomes a key enabler of management actions that may mitigate risk, manage cost, and manage schedule. For example, the development of iterative estimates of final contract costs, beginning with the initial BAC and ending with the last Latest Revised Estimate (LRE), rates as both management control and risk moderator. Effective EVM systems impart upon a program at least a modicum of visibility into subcontractor performance, performance that directly affects the prime contractor (Scott, 2005).

Having seen the benefits of proper guideline adherence, and how these yet-to-be-defined guidelines evaluate an EVMS, the next section contains an overview of the ANSI EVMS guidelines.

### *c. The ANSI/EIA-748-A-1998 EVMS Criteria*

Although ANSI's EVMS Criteria may have changed in name and wording over recent years, their intent has remained largely unchanged since their inception.

“Each criterion addresses a major principle necessary for effective management of large, flexibly priced defense projects…criteria are often described as common-sense management practices that any well-managed defense contractor would use” (Christensen, 1998). Table 1 provides a concise list of the 32 criteria.

| Criteria | |
|---|---|
| **Group 1: Organization** | |
| 1 | Define authorized work (WBS elements) |
| 2 | Identify organizational responsibilities |
| 3 | Integrate the system |
| 4 | Identify overhead management |
| 5 | Provide for performance measurement |
| **Group 2: Planning, Scheduling and Budgeting** | |
| 6 | Schedule the work |
| 7 | Identify products, milestones and indicators |
| 8 | Plan the Performance Measurement Baseline (PMB) |
| 9 | Establish budgets for work |
| 10 | Identify work packages |
| 11 | Summarize work package budgets to control accounts |
| 12 | Identify and control level of effort |
| 13 | Establish overhead budgets |
| 14 | Identify management reserves and undistributed budget. |
| 15 | Summarize budgets to target cost |
| **Group 3: Accounting** | |
| 16 | Record direct costs |
| 17 | Summarize direct cost to the WBS |
| 18 | Summarize direct cost to the organization |
| 19 | Record indirect costs |
| 20 | Identify unit/lot costs |
| 21 | Record material costs |
| **Group 4: Analysis** | |
| 22 | Identify schedule and cost variances |
| 23 | Analyze schedule and cost variances |
| 24 | Analyze indirect costs |
| 25 | Summarize data elements and variances for reporting |
| 26 | Implement managerial actions |
| 27 | Develop revised estimates of cost at completion |
| **Group 5: Revisions** | |
| 28 | Incorporate changes into plans, budgets and schedules |
| 29 | Reconcile budgets changes |
| 30 | Control retroactive changes |
| 31 | Control revisions to the program budget |
| 32 | Document changes to the PMB |

Table 1. ANSI/EIA-748-A-1998 EVMS Criteria

As presented within Table 1, ANSI/EIA-748 organizes the criteria into the following five areas based on major project management activities:

- Organization
- Planning, Scheduling and Budgeting
- Accounting
- Analysis
- Revisions

The *Organization* area (five criteria total) covers the definition of authorized work within a program. It also tasks program planners to ensure some effective delineation of organizational structure and their respective responsibilities. Finally, this area stipulates some integration of the program's work with the organizational structure that enables effective and meaningful measurements of cost and schedule performance.

The second area, *Planning*, *Scheduling and Budgeting* (ten criteria total), contains information regarding proper planning, scheduling and budgeting of authorized work so information gleaned from the system remains meaningful. Specifically, this area supports and explains the ideas of task interdependency awareness; milestones, delivery criteria, and other measures of progress; and benefits of stable and measurable units. It also references some areas of customer interaction.

The *Accounting* area (six criteria total) includes a discussion of maintaining accounting discipline so information remains comparable from reporting period to reporting period. Not surprisingly, this area also discusses direct costs, indirect costs, and unit costs as they pertain to a formal EVMS. Additionally, this area discusses the integration of a material accounting system with the planned EVMS.

The next area, *Analysis* (six criteria total), suggests the frequency of submitting EVMS reports (at least monthly) and what basic data to include (ACWP, BCWS, BCWP, SV, CV). It also presents customer reporting requirements and prerequisites for delivery of a meaningful management control product. This area also examines implementing changes based on important identified variances.

Lastly, *Revisions* (five criteria total) discusses how EVM practitioners should incorporate changes to reports, thereby enabling timely and effective changes to an affected program. This area also explains the difference between appropriate changes (e.g., correction of errors) and inappropriate changes (e.g., hiding flawed information). *Revisions* sets forth that practitioners should always document changes.

With the concept of EVM explained, the next section contains an introduction to the F-22 program.

### 2. The F-22 Program

In the summer of 2002, F-22 System Program Director (SPD) Brigadier General William J. Jabour confirmed what other program officials had cautiously hinted at for several months: the F-22 would miss its scheduled start date for the program's Dedicated Initial Operational Test and Evaluation (DIOT&E) (Chapman, 2002). With internal pressure from Air Combat Command already mounting and external pressure in the form of congressional involvement imminent, the timing could not have been worse for the forecasted six month schedule slip. Senior DoD leaders demanded to know how such a monumental program failure could occur without warning and talked of ominous consequences should another slip transpire.

Regardless of these pressures to maintain schedule, a fact-finding group known as the Red Team (assembled by concerned program proponents) arrived at a threatening conclusion: the program would slip again. The situation reached critical mass during the close of 2002, when Secretary of the Air Force, Dr. James G. Roche, reassigned Generals Jabour and Shackelford in favor of “new leadership…necessary to achieve the Air Force’s objectives” (Air Force Print News, 2002). Internally, Air Force leadership wondered how this could happen, since the program performance measurement practiced by the F-22 program (i.e., Earned Value Management) should catch impending cost and schedule problems early in the process.

In fact, three years earlier the Government Accountability Office (GAO) found that the F-22's prime contractor, Lockheed Martin, retained reports exhibiting a downward trend with respect to its accomplishment of planned work.[6] Specifically, software development (i.e., avionics' Operational Flight Program (OFP)) for the F-22 fell behind to such an extent that a rebaselining of schedule occurred on August, 1998. According to the GAO (1999), the causes included: avionics development falling behind schedule, unrealistic avionics schedule goals, and the critical nature of avionics with respect to the weapon system.

This schedule slip for one of DoD's largest weapons system acquisitions joined a long list of timeline adjustments to the right. Numerous program slips occurred over the F-22's twenty-plus years of development. Figure 1 shows F-22 program milestones compared to other legacy aircraft development efforts. The cumulative effect of all F-22 schedules slips resulted in the program taking "76 percent longer than estimated to achieve first flight and 57 percent longer to reach first production [and] 19 percent longer to reach Initial Operational Capability (IOC)" (Younossi, Stem, Lorell, & Lussier, 2005). One driving factor is persistently manifested behind each and every scheduling failure: avionics development.

[6] As of June 1998, LMT estimated planned work not completed at $115M.

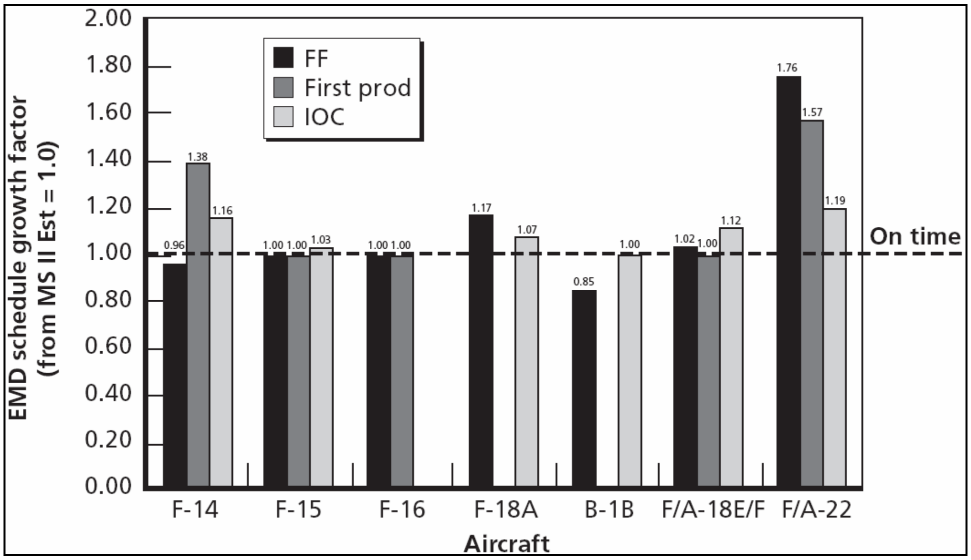


Figure 1. F/A-22 Schedule Slippage Is Higher Than the Historical Average (From: Younossi et al., 2005)

Officially designated today as the F-22A, the program (formerly known as the Advanced Tactical Fighter, F-22, and F/A-22) has undergone dramatic mission requirement changes since its inception in the late 1980's. Originally, US leadership envisioned the F-22 as an answer to the Soviets' Su-27 and MiG-29 aircraft that threatened to technologically usurp the global dominance of the Boeing F-15 fleet. However, in the eyes of budget hawks the fall of the Soviet Union (and subsequent termination of the Cold War) changed the requirement for a next generation air-to-air platform. Many questioned the need to move away from the historical dominance of the current F-15 fleet in a world lacking adversarial nation-states with upgraded, current generation fighter aircraft.

This new global reality forced the Air Force to move away from a strict air-to-air role and instead introduce air-to-ground requirements to the F-22 program. While the advanced air-to-air capabilities of stealth, supercruise, and integrated avionics remained the foundation of the revolutionary fighter, the program solidified plans that would incrementally add additional capabilities such as delivery of Joint Direct Attack Munitions and enhanced air-to-ground radar to the jet. As a result, the Air Force directed the F-22 System Program Office (SPO) to initiate a new Modernization program, with its main objective being the development of in-line and post-production upgrades to the fighter. Though joint SPO and Contractor Team plans to integrate a majority of these new requirements looked to post-EMD, several key requirement changes required introduction and implementation prior to completion of both EMD and approval to proceed with Full Rate Production (Younossi et al., 2005).

While many defense experts typically point to the introduction of these new requirements as a key driver behind the schedule slips and accompanying cost over-runs, others note that the F-22 experienced significant cost and schedule variances prior to introduction of these additional requirements. For example, according to a 2006 study by Younossi et al., "[F-22] cost growth was mainly the result of design challenges in the airframe (arising from stealth requirements), the integrated avionics suite, and the new propulsion system." Figure 2 highlights this statement by presenting the cost growth of the F-22 by major system from 1995 through 2002.

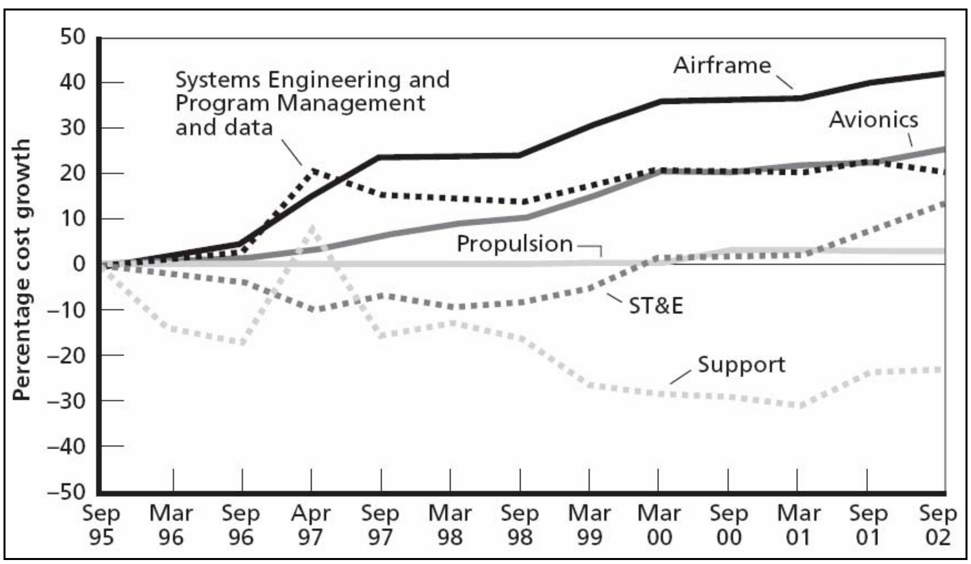


Figure 2. F-22 Cost Growth Trends for Major Systems
(From: Younossi et al., 2005)

Looking at percentage of cost growth alone rates the F-22's integrated avionics suite as one of the areas of greatest concern. The highly complex avionics subsystem, touted as one of the three key technological advancements contributing to the dominating existence of the F-22, certainly explains that cost growth.[7] After all, advancements such as those fielded in the avionics suite do not come without an appropriate price tag. In fact, government experts calculated this subsystem consumed one-third of the F-22 program budget—"more than any other subsystem, including the airframe" (Younossi et al., 2005). This still leaves the question of "What happened that caused such price growth?"

One answer may lie in a comparison of the historical development of avionics systems and the F-22's systems. While legacy aircraft avionics followed a federated construct where each avionics subsystem (e.g., Communications / Navigation / Identification, Electronic Warfare, Radar, etc.) provided information to the pilot independently from other subsystems, the F-22 uses a central core processor to fuse this information from the various sensors and other components to present an integrated picture to the pilot. This requires extremely large numbers of instructions per second—millions for data processing and billions for signal processing—creating extensive demands on aircraft computing systems that resulted in significant system lock-ups during developmental testing (GAO, 2004).

In addition to the extreme demands on avionics hardware, the F-22 requires software complexity at an unprecedented level to manage the data flowing through said hardware. Software designers answered that need with the F-22 Operational Flight Program. But once again, increasing complexity and requisite robustness became another driver that increased avionics cost. Between October 1993 and April 2000 the F-22 Software Lines of Code (SLOC) grew approximately 34 percent (Younossi et al., 2005). According to the GAO, this SLOC growth, largely driven by requirements and design changes, resulted in delayed software deliveries, impacting program cost and schedule,

[7] The other two F-22 "first look, first shot, first kill" capabilities identified as "firsts" in US military aircraft are supercruise and stealth. The powerful F-119 engines and airframe design provide supercruise capability, enabling the F-22 to cruise at supersonic speeds without the use of afterburners. Although other aircraft have fielded stealth technology, the F-22 is noted as being the US first all-weather, "24-7-365" stealth tactical fighter.

and “accounted for 37 percent of the critical problems reports leading to avionics shutdowns in the [F-22].” (2004)

Conventional wisdom supports the idea that the Air Force—not to mention other services—would like to avoid similar situations in the future. Aiding that desire became the ultimate driver behind this study. The next section, *Purpose and Significance of Study*, further explores the motivating forces behind this research.

## B. PURPOSE AND SIGNIFICANCE OF STUDY

Within the context of this study, two goals remained paramount and thus defined the project’s purpose. The first goal: determine if current EVM implementation within the F-22’s Modernization program will likely prevent an abrupt schedule slip and certain-to-follow cost overrun—similar to what occurred during EMD. The second goal: make meaningful recommendations, where appropriate, with the objective of strengthening the current EVM system implemented to measure the F-22 program’s software development performance. Again, these goals delineate the study’s purpose.

The significance of the study relied upon the expectation of ever-increasing weapon system complexity, especially within the realm of software integration. For example, upon completion of a Program Office Estimate (POE) on March of 2003, the government predicted F-22 EMD costs to exceed Milestone II estimates by 33 percent. Granted, a program spanning an inordinately large number of years should expect to see mission requirement and technology changes that drive schedule and cost impacts, however, the F-22 actually fared worse than the average of other similar development efforts, with a schedule growth factor of 1.33 versus a 1.22 average (see Figure 3 below).

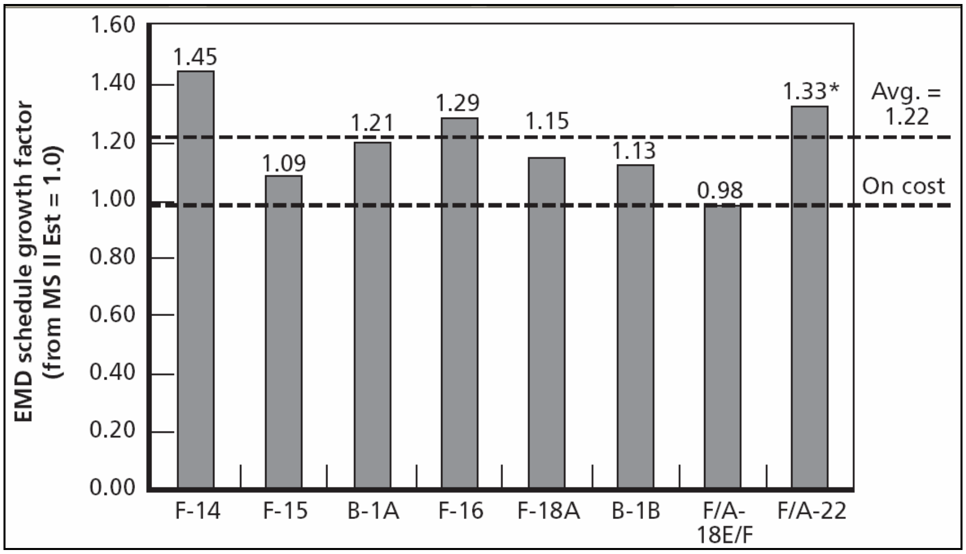


Figure 3. F/A-22 Cost Growth Is Higher Than the Historical Average (From: Younossi et al., 2005, p. 10)

As evidenced within the first section, *Background*, avionics development rated as a significant cost driver. When considered concurrently with the schedule trials experienced during EMD, these facts escalated the importance of discovering whether or not the EVMS implemented-of-late worked to minimize the schedule and cost risks of an unprecedented software effort. More importantly, given the increasing cost of warfare-dominating technology, DoD should address this prior to reaching comparable phases of development within upcoming flagship acquisitions: the Joint Strike Fighter and the Future Combat System. According to the GAO, these two programs are projected to cost DoD over $330B — more than five times the total cost of the F-22 program and roughly 80 percent of DoD's entire FY07 Appropriation Bill (2006).

Thus, learning from mistakes of the past becomes vital within DoD's resource-constrained environment. Seeking significant answers lies in asking pointed questions. First, if the F-22 program office practiced and used EVM, how did these problems appear to catch everyone (but program detractors, of course) by surprise? Lastly, why weren't the abrupt cost overruns and schedule failures, that cost an SPD his job, caught earlier? The next section, *Research Questions*, further explores and refines these questions by putting them into the context of this study.

## C. RESEARCH QUESTIONS

Finding answers to a problem entails first defining the problem. Three direct questions defined the problem-at-hand by asking:

- How closely did the F-22 Spiral 2 implementation of EVM follow the criteria outlined in ANSI/EIA-748 Earned Value Management System?
- To what degree did the F-22 Spiral 2 implementation of EVM fulfill its role as a management control system for avionics software development?
- To what extent did the F-22 Spiral 2 program management (Government and Contractor) use EVM products to manage avionics development efforts?

Answering these questions assessed the F-22 program's use of EVM in managing avionics software development from a current (Spiral 2) perspective. The section-to-follow describes the approaches taken to answer these questions and, more importantly, explains why this subject matter was chosen for academic research.

## D. METHODOLOGY

This section begins with a brief explanation of why the F-22 Spiral 2 program was chosen as a representative case study of the interaction between DoD software development and the EVMS that measures its progress. As established in the previous section, three questions essentially frame the research problem; this section concludes by matching these same questions with their primary answering method.[8]

Why choose the F-22 Spiral 2 program as a case study? The first and foremost reason: <u>access</u>. Utilizing the professional relationships and contacts resulting from prior experience at the F-22 SPO greatly enhanced the probability of both a successful research effort and the delivery of useful recommendations. Access eased not only asking the

[8] The primary distinction was made since, in reality, each answer more or less utilized a mix of methods, with the primary method answering the majority of issues relating to its respective question.

questions and collecting answers; it facilitated the project with the knowledge of whom to ask.

Along the same lines, the first-hand knowledge and direct observations gained from prior experience at the F-22 SPO created a sense of familiarity within the context of a research project seeking an unknown answer.  This fomented a synergistic effect between knowledge gained while attending the Naval Postgraduate School (NPS) and the knowledge already possessed of EVM standard operating procedures at the F-22 program.  Consequently, this allowed the research to move beyond basic concepts and into the world of practical application, even prior to the information gathering phase.

Another reason that supported studying the F-22 program was the program's pending universality.  Simply stated, pending universality means that the F-22 program's software development exhibits trends[9] that experts believe will become commonplace in future DoD acquisition efforts.  As such, having studied the interactions between unprecedented software development and EVM, resulting universal concepts (i.e., concepts applying to all programs, regardless of function) from the study should at least partially transfer to upcoming programs.

The final reason behind choosing the F-22 program proved less complicated:  the simple desire to help.  The lack of clear-cut answers to the research problems, even with previous experience with the program, fostered unease with respect to EVM implementation within software development programs.  Only after the attainment of new academia-based knowledge while attending NPS (e.g., Acquisition, Cost Estimation, and Research courses) was it felt that a helpful answer could become perceptible.

In summary, the F-22 Spiral 2 program was chosen as the program-of-study due to its relative ease of access, familiarity, pending universality, and a desire to help the program.  The following paragraphs concern the applications to the research problems introduced in the earlier *Research Questions* section.

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[9] Specifically, the Joint Strike Fighter and Future Combat System both exhibit similar degrees of software complexity resulting from the weapon systems' increased dependency on software and integrated constructs.

Answering "How closely did the F-22 Spiral 2 implementation of EVM follow the criteria outlined in ANSI/EIA-748-A-1998 Earned Value Management System?" relied mainly on a careful assessment of how EVM implementation for Spiral 2 supported the 32 ANSI/EIA criteria. The text *Earned Value Project Management* by Fleming and Koppelman provided a majority of the assistance through its detailed description of each of the criteria. Those descriptions were aligned with procedures in place within the F-22 software program, in turn identified by interviews, portions of the questionnaire, and collected management documents. The degree of alignment answered the question for each of the criteria.

"To what degree did the F-22 Spiral 2 implementation of EVM fulfill its role as a management control system for avionics software development?" was answered primarily by data collection. Specifically, Cost Performance Reports (CPRs) directly related to Spiral 2 efforts were distilled into raw cost and schedule measurements. A complete EVM analysis was accomplished and compared to outputs from SPO and GAO reports, in addition to testimony from individuals involved. The comparison, in essence, answered the question.

Lastly, the EVM Questionnaire answered the question "To what extent did F-22 program management (Government and Contractor) use EVM products to manage avionics development efforts?" The questionnaire aimed to assess the perceived usefulness of EVM within a software development context. If a given respondent answered positively to that question, they were asked to rate the practical value of EVM with respect to their program management duties. Interviews supplemented the data from the questionnaire, figuratively filling in the questionnaire's information gaps uncovered throughout the course of the research project.

In summary, accomplishing this project involved conducting interviews with subject matter experts, both at the F-22 SPO and Lockheed Martin, to assess their thoughts on exactly how well the program followed the ANSI/EIA-748-A-1998 guidelines. In addition, results from the EVM Questionnaire were reported, along with deduced conclusions. This questionnaire surveyed occupational specialties involved with software development efforts, and summarizes opinions and knowledge related to EVM and ANSI/EIA-748-A-1998. Finally, data and report collection assessed the information provided by, among other sources, the avionics development's EVMS.

## E. FRAMEWORK

Chapter I, *Introduction*, served three main purposes. First, the chapter provided context by discussing the history of avionics development within the larger F-22 development effort (see the *Background* section). Second, it revealed the paper's purpose and why this study may prove significant to future DoD efforts. Finally, it established an academic framework by identifying the problems this paper seeks to answer and how it answered them (see the *Research Questions* and *Methodology* sections).

Chapter II, *Literature Review*, provides an informed foundation by examining current bodies of work that discussed applicable topics. Since research efforts focused on both software development and EVM, relevant information included references to suitable texts containing foundational thinking associated with these two topics—to include a basic primer for EVM. Additionally, contemporary ideas regarding the interaction between EVM and software development were explored.

Chapter III, *F-22 Implementation of ANSI/EIA EVMS Criteria*, highlights the 32 ANSI criteria. Using those criteria—as explained in the *Earned Value Project Management* text—an assessment was made of EVM implementation within F-22 software development. Each criterion was analyzed separately and a conclusion was reached regarding the degree of alignment between implementation and its intended purpose.

Chapter IV, *F-22 EVMS Environment*, examines the recent and current environment of EVM as it pertains to F-22 software development. This chapter seeks to consolidate questionnaire responses, interviews, observations, data collected, and the authors' experiences regarding how the F-22 program applies EVM to software development. Specifically, the chapter aims to provide insight into how the current avionics contract environment, avionics suppliers, and recent avionics programs themselves may or may not contribute to difficulties in EVMS implementation.

Chapter V, *Conclusion*, presents a condensed synopsis of this research project's outcome, includes a brief discussion on limitations with respect to the research project, and makes final recommendations to the EVMS where necessary. According to this paper's research, these recommendations (if required) should serve to strengthen the F-22 avionics program's EVM system.

## F. SUMMARY

This concludes Chapter I, *Introduction*. The next chapter, *Literature Review*, introduces the reader to existing academic works associated with Software Development, and EVM, and the interaction between the two. Chapter II also includes further background on F-22 avionics software development.

# II. LITERATURE REVIEW

## A. PREFACE

This chapter strives to take the research topic, *An Analysis of Earned Value Management Implementation in the F-22 System Program Office's Software Development*, and provide the reader with an informed and expert-based framework using a diverse collection of reports, papers, data, and experience. Providing the framework itself entailed examining existing bodies of work that discuss the following:

- Unique Aspects of Software Development
- Lessons Learned Regarding the F-22 Program and Software Development
- Current F-22 Software Development Strategy—Spiral Modernization

A completed analysis of these three areas will not only set the stage for the remainder of the paper, it will also enable the reader to begin framing desired scenarios against the backdrop of these real-world challenges and processes.

## B. UNIQUE ASPECTS OF SOFTWARE DEVELOPMENT

### 1. Software Development Challenges

Today the F-22 exists as one platform amid an exploding population of DoD equipment now relying heavily on software to perform their respective missions. Even so, the F-22 remains a precursor to the major defense weapons systems of tomorrow through its use of complex, embedded software. Consider the following: according to a Defense Science Board's Task Force on Defense Software report (2000), military aircraft dependency on software increased from approximately 10 percent functionality on the F-4 to 80 percent functionality on the F-22—equivalent to a 2 percent per year increase (1960-1995). Simply stated, software has become ubiquitous within DoD acquisitions, and today's high tech machines of war, in fact, depend on it at unprecedented levels.

For example, even DoD's historically "dumb" weapons—items such as air-to-ground bombs and artillery rounds—rate modernization funding to equip them with advanced systems that boost functionality, precision, and lethality. However, equipping such munitions with GPS systems and autonomous guidance technologies predictably increases their own reliance on software to perform their functions.[10] As a result, a given increase in performance causes some commensurate increase in complexity and risk (i.e., the inherent trade-offs between performance, schedule, and cost).

A 1999 study performed by the Standish Group (an organization that studies information technology investments) brought attention to this suspected trend. The study found 31 percent of commercial, DoD, and combined commercial-DoD software development efforts resulted in cancellation. In addition, the study reported the following software development statistics (GAO, 2004):[11]

- Cost overruns of 189 percent
- Schedule delays of 222 percent
- Delivery of 61 percent of originally specified features or functions

In an attempt to find some root cause of these dismaying statistics, the Defense Science Board, once again, investigated the area of software development. The Board found that software-intensive "programs lacked a well thought-out, disciplined program management and/or software development processes." The findings went on to state that "meaningful cost, schedule, and requirements baselines were lacking, making it virtually impossible to track progress against them" (2000).

Exploring this concept further involves analyzing the key differences between hardware and software development. For instance, when compared to hardware, software tends to propagate change effects at a higher rate. Furthermore, software exists more in the intangible realm of data and logic, versus physical components. Finally, software has

10 Examples are the US Air Force Small Diameter Bomb (SDB) and US Army Excalibur weapons. The SDB program is a 250-lb class guided munition currently under development at the USAF Air Armament Center (Picatinny Arsenal News Release, 2005). The US Army's Excalibur program is a howitzer-fired munition that uses GPS to guide (in flight) to within 10 meters of its target (Ruscetta, 2005).

11 Percentages were based on comparison with initial baseline.

limited standardized design methods, components or structure when matched up against hardware.

These differences mean that a typical software development project underestimates the development schedule when planners employ methods used to predict non-software development. It appears the very nature of software causes development issues that translate into cost, schedule, and performance concerns. Therefore, while labeling a development effort as "hardware" certainly does not grant immunity from these challenges and critiques, the complexity and prevalence of embedded software in weapons systems heightens the probability that problems do occur.

Software's nature does not completely differentiate itself from hardware, however. Software, in many cases, requires full integration with hardware. As such, it must share at least some fundamental characteristics with hardware to facilitate said integration. The Defense Acquisition University (DAU) stated that some of the key similarities between hardware and software include: functional decomposition; traceability to system requirements; accountability by task; progress monitoring; and reliance on operating principles and constraints (2006).

As for DoD specific studies on the matter, the Acquisition, Technology, and Logistics (AT&L) Knowledge Sharing System (AKSS) summarized the typical problems defense acquisition programs have encountered over the years. For one, the dynamic and rapidly evolving nature of software development makes it difficult to adhere to an original baseline. Program managers and other decision makers lack basic software knowledge, which only aggravates the problem of baseline adherence.

Similarly, end-product-users typically cannot accurately convey requirements, and promulgate requirements creep[12] throughout the development phase (once again hampering the baseline). This problem in turn leads to joint software and hardware development either starting or becoming uncoordinated, either directly because of poor or

[12] "A tendency for product or project requirements to increase during development beyond those originally foreseen, leading to features that weren't originally planned and resulting risk to product quality or schedule" (Johnson, 2005).

non-existent software development metrics or as a result of inadequate software testing programs.

AKSS provides a final assertion that effectively creates a foundational predicament with respect to the previously listed problems. DoD personnel generally (with few exceptions) lack fundamental software development knowledge: that dearth of knowledge will continue into the foreseeable future until DoD can effectively compete with the private industry for software engineers.

This segment contained a brief discussion of software development challenges; the next topic concerns the distinctive software development lifecycle, and uses this context to further compare and contrast software with hardware.

### 2. Software's Lifecycles

Fundamental characteristics aside, other differences pertinent to this paper exist between hardware and software development. Professional organizations such as the Carnegie Mellon Software Engineering Institute (SEI) and the USAF Software Technology Support Center (STSC) recognized this and bestowed a unique lifecycle upon software development separate from hardware development. Although different than the lifecycle phases typically imparted to classic hardware-intensive efforts, note the similarities and parallels between the phases of the software lifecycle and those of hardware (2005; 2003):

- **Requirements** – Through interfacing with the customer, the developer analyzes operational problems or needs and translates them into functional requirements. This Systems Engineering process results in lower-level, detailed functional requirements traceable to higher-level requirements. Contrast to *Concept Refinement* and *Technology Development* within the Acquisition Framework (Figure 4).

- **Design** – This phase involves definition of the software structure. It analyzes specific solutions and approaches and chooses the best alternative based on cost, schedule and performance parameters. Two design reviews within this phase typically approve the Preliminary Design (the initial software architecture) and the Detailed Design (functional modules and interfaces). Contrast to *Technology Development* and *System Development and Demonstration* within the Acquisition Framework (Figure 4).

- **Implementation (Development) –** This phase involves actual coding of software. Coding usually entails an iterative approach consisting of subsystem (component) unit development and testing prior to integration testing within the main software build. Results from that testing in turn help develop yet another round of coding. Contrast to *System Development and Demonstration* within the Acquisition Framework (Figure 4).

- **Testing –** This phase typically involves three types of testing: Unit Testing, Integration Testing, and Acceptance Testing. As discussed above, accomplishing the first two types entails many cyclical trials prior to proceeding with acceptance testing, which verifies performance against requirements. Contrast to *System Development and Demonstration* within the Acquisition Framework (Figure 4).

- **Deployment –** Anticipate this phase to field the software product in its intended environment. Also, users become familiar with the system via training. Once complete, it finalizes the system development effort. Contrast to *Production and Deployment* and *Operations and Support* within the Acquisition Framework (Figure 4).

- **Maintenance –** Depending on the need for enhancement, fixes, or modifications, this phase ranges in scope from a minimal to a Herculean effort even larger than the original development. This phase typically costs far more than the original development effort. Changes in software this late in development come with a heftier price tag than the same effort undertaken during an earlier phase. Contrast to *Production and*

*Deployment* and *Operations and Support* within the Acquisition Framework (Figure 4).

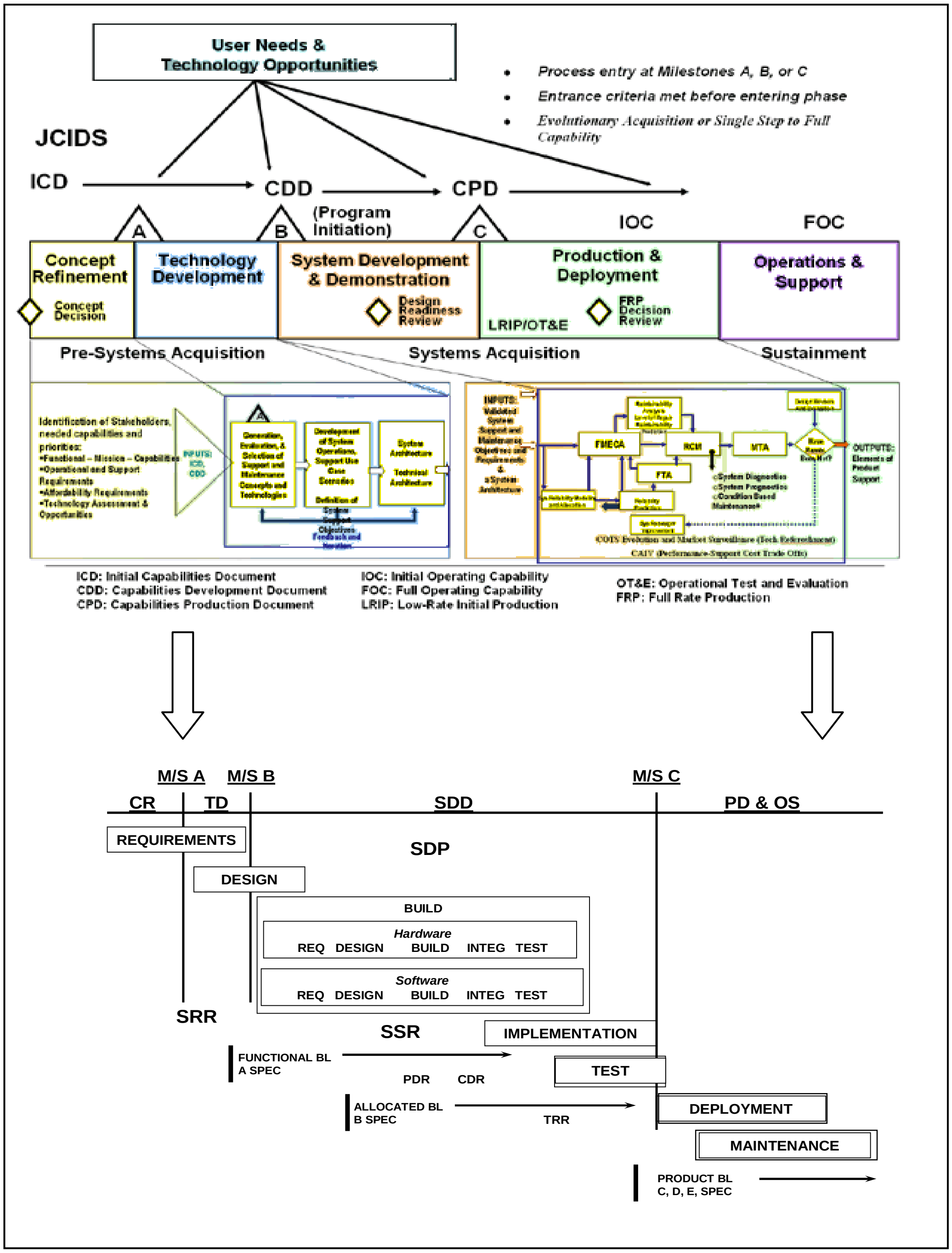


Figure 4. Comparing Defense Acquisition Management & Software Acquisition Framework

(From: AT&L Knowledge Sharing System, 2006; MN3301, 2006)

As alluded to within the previous section, one of the inherent challenges with software development efforts lies in premature migration into the implementation phase prior to sufficient completion of the requirements and design phases. In an assessment of commercial software development companies, the GAO identified best practices that included the need for management to protect against missing, vague or changing requirements that negatively impact programs. Using commercial industry as the standard, GAO identified a benchmark of setting 95 percent of requirements by the end of the requirements phase, and 98 percent by the end of the design phase (GAO, 2004). For the military, the need for fully defined and stable requirements presents a unique challenge. In its report to the Secretary of Defense in 2006, the Defense Acquisition Performance Assessment panel stated the following:

> The [DoD] Acquisition System must deal with external instability, a changing security environment and challenging national security issues. The Department must be agile—to an unprecedented degree—to respond quickly to urgent operational needs from across the entire spectrum of potential conflicts. (p. 7)

Balancing this need for flexibility against the recognized need for requirements stability in software development heightens the need for flexible, disciplined program controls within well-managed programs.

Defining and understanding the different phases of the software lifecycle is only the first step to successfully managing a software program. As with any project planning effort, managers must identify those critical factors necessary to determine a software program's success or failure. The five critical factors identified by the Air Force's STSC are: Quality, Cost, Schedule, Performance and Supportability. For each of these factors, the project manager must develop appropriate plans, criteria, expectations, measures and controls to ensure the program stays on course. Since its inception, EVMS has proven a powerful tool for measuring and controlling the factors of cost and schedule. Although it "requires a fully defined project up front and bottom-up cost estimates…it can provide accurate and reliable indication of cost performance as early as 15 percent into the project" (STSC, 2000).

This section defined and represented the difficulties implicit within a software development program. The next section discusses the performance measurement of software development within the context of the F-22 program.

## C. LESSONS LEARNED REGARDING THE F-22 PROGRAM AND SOFTWARE DEVELOPMENT

Current research pertaining to measuring the progress of software development supports the assertion that, in the initial stages of development, software efforts track much like their hardware counterparts. In other words, it is relatively easy to apply EVM to the first two phases—Requirements and Design. However, this assumes that the program in question has adequate cost and schedule controls.

Two recent assessments of the F-22 program provided recommended changes regarding the interactions between its software development and its EVMS. Between the assessments exists a common theme: the program needs better cost and schedule controls. The first report was written by the Government Accountability Office (GAO); the RAND Corporation generated the second report.

In its 2004 report, *DEFENSE ACQUISITIONS: Stronger Management Practices Are Needed to Improve DoD's Software-Intensive Weapon Acquisitions*, the GAO recommended DoD require its software-intensive development contractors to first collect and regularly report metrics related to software cost, schedule, size, requirements, tests, defects and quality. In its next recommendation, the GAO suggests that DoD, in cooperative effort with its contractors, develop "an earned value management system that reports cost and schedule information at a level of work that provides information specific to software development."

More recently, in 2005 Younossi et al. identified in *Lessons Learned from the F/A–22 and F/A–18E/F Development Programs* the need to have EVM data "monitor and manage program costs at the level of integrated product teams." However, merely stating these controls should be put in place doesn't necessarily equate to examination and understanding of all implications related to the complexities of applying EVM. This is especially evident when considering the complex, dynamic, and unique characteristics of software development.

Avionics remains a critical and arguably the most-complicated system of the F-22. It heavily impacts both cost and schedule, and has done so over a significant period of the program. Both program and contractor officials admitted that the program failed to follow their stated software strategy: to collect metrics and manage to those metrics. This failure facilitated the loss of program cost and schedule control. Further investigation revealed that other cost and schedule pressures within the F-22 program contributed to a failure of desired software metrics. These pressures kept the program from providing its managers the necessary metrics for sufficient oversight of the overall progress of software development efforts (GAO, 2004).

## D. CURRENT F-22 SOFTWARE DEVELOPMENT STRATEGY – SPIRAL MODERNIZATION

As discussed in the previous chapter, the F-22 program has undergone significant external pressures requiring adaptation to changing strategic and tactical threats, even while fighting for funding from shrinking DoD budgets. All this while developing one of the most technically complex systems fielded to date by DoD. These schedule pressures, changing requirements, technical risks, and funding instabilities haunted the F-22 EMD program through its conclusion in 2005. With the need to deliver unmet EMD requirements and modernize the fighter to meet emerging threats, Air Force leadership initiated a follow-on effort to EMD in 2003.

Unlike its predecessor, the F-22 Modernization Program was not contracted under one behemoth contract. Rather, it was contracted with Lockheed Martin Aeronautics (LM Aero) under an Indefinite Delivery Indefinite Quantity (IDIQ)[13] contract titled the *Raptor Enhancement Development & Integration (REDI) Contract*. The REDI contract, modeled after a highly successful C-17 modernization contract, would serve as the single

[13] The Federal Acquisition Regulation (FAR) defines an IDIQ as "a contract for supplies that does not procure or specify a firm quantity of supplies (other than a minimum or maximum quantity) and that provides for the issuance of orders for the delivery of supplies during the period of the contract" (Subpart 16.501-1).

contract for “planning, analysis, design, development, qualification, test and documentation of performance enhancements” necessary for the F-22 mission (F-22 System Program Office, 2003). Once awarded, the basic IDIQ contract would authorize work via individual delivery orders focused on specific tasks or development efforts. The magnitude of the delivery orders varied, ranging in value from several hundred thousand dollars to several hundred million dollars.

The first delivery order (DO 0001) awarded under the new REDI contract was the System Engineering/Program Management effort. This DO was the starting point for any enhancement considered for the F-22 and charged LM Aero “to provide overall Systems Engineering and Program Management in support of the F/A-22 program to maintain effective incorporation of changes into the weapon system” (F-22 System Program Office, 2003). It also served as the overarching architecture, accomplishing all early and up-front analysis on an enhancement candidate before committing additional resources and formally proceeding with a stand-alone delivery order. Therefore, DO 0001 is where Spiral 2 found its start.

In 2002, when the F-22 program was still three years from completing EMD, its users began looking forward to what the fighter jet would look like when it was declared mission ready at IOC; the users realized it would fall short in some capabilities. As these capabilities were identified, quantified, and prioritized, a list began to emerge that would define the first upgrade to the jet one year after IOC declaration in December 2005. The upgrades focused on a software-only evolution to the avionics Operational Flight Program. Although the upgrade was later identified by LM Aero in more accurate terms as Block 20, the government organizations and documentation continued to call the program by the original name, a name that captured one of the latest buzz words in DoD acquisition—Spiral 2.[14]

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[14] Spiral 2 is not a spiral product as the name would imply. While each spiral of the F-22 modernization program built on the preceding spirals capabilities, the upgrades more closely resembled increments versus spiral releases. In 2004 considerable discussion between the F-22 program and senior Air Force leadership centered around the correct terminology for the modernization upgrades. In the end it was decided to continue to call them spirals while they would be managed internally by government and contractor personnel as block upgrades.

With EMD and the IOC baseline representing Spiral 1, Spiral 2 represented the first of several upgrades planned for the jet in the modernization program. As the pathfinder, Spiral 2 established the procedures and template for the much larger and more complex software/hardware upgrades of Spirals 3 and 4 that would follow. In March 2003, within the scope of DO 0001, requirements analysis for Spiral 2 started creating a list of potential enhancements called candidates. These candidates were further developed and carried forward to the end of this phase based on several constraints: user priority, available funding, and schedule alignment. As stated above, Spiral 2 was a schedule driven upgrade that planned to deliver software-only upgrades to the OFP not-later-than one year after IOC—or December 2006. These constraints—along with funding limitations—would eventually narrow the list to a handful of approved candidates to carry forward to the follow-on delivery order. Spiral 2 completed requirements analysis in May 2004 and was ready for the next phase of the program.

Not only was the modernization contract broken into individual contract vehicles called delivery orders, but the larger spiral upgrades were broken into different delivery orders. The plan developed for the spirals accomplished requirements analysis on DO 0001. Next a separate delivery order was awarded for the detailed design of the upgrade. Upon completion of the design effort, another delivery order would be initiated to accomplish the coding, integrating, developmental testing and post-operational test updates to the upgrade. This would lead to a modification to the production contract that would field the completed product. Although this process resulted in tremendous pressures on the business processes in the program, it afforded the program the flexibility to adapt to the pressures that caused EMD to flounder so many times. As funding realities changed, as technology challenges were realized, and as requirement priorities shuffled, each transition between delivery orders enabled "on-ramps" and "off-ramps" for capabilities.

For Spiral 2, the second contract effort was DO 0002. This contract was started in March 2004 and included all tasks necessary to accomplish Preliminary Design Review and Critical Design Review for the candidates identified in the contract. This was the first stand-alone Spiral 2 delivery order and utilized EVM as a management tool for the duration of the contract. Unfortunately, the fluidity of requirements and funding combined with the lengthy timelines associated with awarding REDI delivery orders (up to ten months from solicitation to award), forced program management involved to award DO 0002 as an Undefinitized Contract Action (UCA). In Chapter IV, *F-22 EVMS Environment*, the impacts of UCAs on a program's EVM will be discussed; prior to that, however, a short background on the use of UCAs seems appropriate.

Lack of funding predictability, emerging technical requirements from the user, and lengthy business review processes were just a few of the challenges facing each incremental upgrade for the F-22. These challenges, combined with competition for business resources, often led to the initiation of efforts using UCAs. A UCA permits the initiation of an effort without a firm (definitized) contract in place.[15]

While this paper does not try to tackle the complex issues surrounding the pros and cons of using UCAs, the risks associated with proceeding under undefinitized contracts makes this method a contracting tool limited to those instances where it is absolutely necessary. Although used by exception, highly scrutinized, and not typically desirable, in the F-22 program, use of this method of contract award has become prevalent.

Even with the inherent speed of a UCA, Spiral 2 DO 0002 was completed in February 2005—two months past the original period of performance. The completion of the detailed design cleared the way for initiation of the software coding and integration phase. This effort was awarded in January 2005 under a partial UCA for DO 0019 on the REDI contract. (The remainder of the effort was authorized under a UCA in March 2005.) As with DO 0002, this effort would proceed for a long duration under a UCA. Unlike DO 0002, it would be definitized (negotiated via a firm contract) prior to its completion. DO 0019 was definitized in October 2005 and is expected to complete in September 2007.

[15] The Defense Federal Acquisition Regulations Supplement (DFARS) defines an UCA as "any contract action for which the contract terms, specifications, or price are not agreed upon before performance is begun under the action" (Subpart 217.7401d).

## E. SUMMARY

This concludes Chapter II, *Literature Review*. The next chapter, *F-22 Implementation of ANSI/EIA EVMS Criteria*, uses the 32 ANSI criteria to analyze each criterion separately and derive a conclusion regarding the degree of alignment between F-22 program implementation and the criterion's intended purpose.

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# III. F-22 IMPLEMENTATION OF ANSI/EIA EVMS CRITERIA

## A. PREFACE

The 32 criteria identified in ANSI/EIA 748-1998 are recognized by both industry and DoD as the minimum standards for establishing a useful, functioning EVMS. Meeting these criteria is critical if an organization is going to be able to successfully use the EVMS as a management control tool. In order to assess the implementation of the EVMS in the F-22 program, these criteria were used to evaluate implementation of the EVMS in the Spiral 2 modernization program. This assessment was not intended to address whether LM Aero EVMS policy and procedures were sufficient. LM Aero has already demonstrated to DoD their processes comply with the criteria via their certification from industry. Instead, this was a subjective, qualitative assessment, based on the criteria objectives outlined by ANSI/EIA, data and procedures gathered from the F-22 program and the authors' direct observations, which looked at how the 32 criteria were actually applied through the implementation of Spiral 2 contracts.

For each criterion an assessment was made resulting in one of five ratings: *excellent*, *satisfactory*, *marginal*, *insufficient* and *inconclusive*. Based on supporting data that exceeded the purpose of its respective ANSI criteria, the following seven criteria were conferred an *excellent* rating: 4, 14-16, 19, 30, and 31. Adequate supporting data that met the purpose of its respective ANSI criteria, led to the following 15 criteria being conferred a *satisfactory* rating: 1-3, 5, 7, 10, 11, 13, 17, 22-25, 28, and 32. Due to supporting data that contained minor material failures related to meeting the purpose of its respective ANSI criteria, the following five criteria were conferred a *marginal* rating: 6, 8, 12, 18, and 27. One criterion, 26, was conferred an *insufficient* rating based on supporting data that contained more than minor material failures regarding its respective ANSI criteria, the following criterion. Finally, an inadequate amount of supporting data for a given ANSI criteria, led to the following four criteria being conferred an *inconclusive* rating: 9, 20, 21, and 29.

The next section contains a more detailed discussion of these assessments for each of the criteria. Specifically, each criterion includes a brief overview of the intent of the criterion (Fleming and Koppelman, 2000), F-22 (LM Aero) policy/procedures for meeting the criteria (Lockheed Martin Aeronautics Corporation, 2005) and a discussion of the authors' assessment for each criterion.

## B. CRITERIA ASSESSMENTS

### 1. Group 1: Organization Criteria

Table 2 summarizes the assessments provided to each of the five ANSI/EIA EVMS Organization Criteria.

| | Criteria | Assessment |
|---|---|---|
| 1 | Define authorized work (WBS elements) | Satisfactory |
| 2 | Identify organizational responsibilities | Satisfactory |
| 3 | Integrate the system | Satisfactory |
| 4 | Identify overhead management | Excellent |
| 5 | Provide for performance measurement | Satisfactory |

Table 2. Assessment of F-22 Spiral 2 Implementation of ANSI/EIA EVMS Organization Criteria

#### a. *EVM Criterion #1: Define the authorized work elements of the program. A WBS, tailored for effective internal management control, is commonly used in this process.*

This initial criterion addresses the necessity of starting a program only after fully defining its requisite efforts. As hinted at within the criterion itself, military acquisition programs require a program-specific WBS which, through its very nature, satisfies this criterion.[16] Consequently, work requested by a customer not identifiable within an already developed WBS should be considered out-of-scope, and the customer and/or contracted organization should seek FAR-approved authorization methods to begin such work (in this case, the Air Force and LM Aero, respectively).

[16] As described per MIL Handbook 881.

With respect to Spiral 2-related work, LM Aero stated that tasks were authorized for accomplishment through modifications to the basic Raptor Enhancement Development and Integration (REDI) contract (via the F-22 SPO's contracting officer). Once signed, these Delivery Orders (DOs) then energized LM Aero's Business Management division to initiate a Sales Order, which by itself serves as notification of task authorization to Spiral 2's management team at Lockheed. The management team analyzed the DOs, Sales Orders, and Statements of Work (SOW) within proposals for the actual allocation of authorized tasks to their appropriate WBS elements. At the direction of ASC/YFK (the customer contracting officer) via a Contract Data Requirements List (CDRL), an official WBS was drafted.

LM Aero communicated that the WBS was structured to conform to the latest version of MIL Handbook 881 and that the WBS includes all Contract Work Breakdown Structure (CWBS) elements specified for external reporting by the CDRL. Direct observation of the Cost Performance Reports (CPRs) supports this assertion. The WBS appeared to capture all authorized work due to the lack of changes to the WBS throughout the lifecycle of the Spiral 2 program. In conclusion, with respect to LM Aero's actions concerning the definition of authorized work for the Spiral 2 program, by meeting this criterion to the letter this EVMS program warrants a *satisfactory* rating.

***b. EVM Criterion #2: Identify the program organizational structure, including the major subcontractors responsible for accomplishing the authorized work, and define the organizational elements in which work will be planned and controlled.***

The Organizational Breakdown Structure (OBS) must be established to ensure that all elements of the WBS (established per Criterion #1), are assigned to a specific organization or individual. The establishment of the relationship between the OBS and WBS results in an OBS/WBS assignment matrix. This product ensures clearly defined responsibility for each task's completion.

LM Aero establishes their OBS according to an Integrated Product Team (IPT) structure. Here each level or tier has IPTs respectively assigned to one IPT above them, ensuring that any IPT will only be subordinate to one IPT (Figure 5 provides an example of the IPT breakout for Spiral 2). This approach enables one element of the WBS to be assigned to one IPT (or major subcontractor). The interface between one organization and one WBS element is what defines a cost/schedule account. While each WBS element may only be assigned to one organization, multiple WBS elements may be assigned to any one organization.

**F-22 DO0002 IPT Structure**

**Air Vehicle**
- Air Vehicle Systems Engineering and Integration Team (SEIT)
- Air Vehicle Systems

**Build Team**
- **Mission System & Software**
  - Avionics SEIT
  - Core Processing
  - Communications, Navigation & IdentificationI
  - Stores Management System
  - Display Products
  - Electronic Warfare
  - Mission Avionics Software
  - Radar

**Sustainment & Modifications**
- Modifications and Heavy Maintenance
- Support Equipment
- Support Data
- Support Services
- Training
- **Weapon System Integration & Technology**
  - Flight Test
  - Flight Termination System
  - Test Plan & Support
  - System Integration

**Program Operations**

**Modernization**

Figure 5. Spiral 2 IPT Breakout

(From: Spiral 2 CPR (Format 2), 2004)

LM Aero appropriately established a detailed OBS/WBS assignment matrix for all Spiral 2 contract efforts. Although the initial delivery order for Requirements Analysis Phase did not establish this product in as much detail as the two follow-on efforts, it did provide the necessary relationship between the WBS elements and organizations assigned to each of these elements. As discussed above, this effort was accomplished as part of an overarching delivery order that encompassed several modernization efforts. As a result, the WBS elements for the Spiral 2 effort were at a higher level than those developed and assigned for the two Spiral 2 specific delivery orders.

Additionally, a critical concern with this criterion that will be repeated for many other criteria is the timeliness of the establishment of the OBS/WBS assignment matrix. The Integrated Baseline Review (IBR)[17] for each of the three Spiral 2 efforts was held significantly later than the initiation of the contract effort.[18] Based on the authors' experience, this was driven by the lack of a definitized contract, changing government requirements and immature modernization processes. The LM Aero cost accounting process made the creation of cost/schedule accounts mandatory in order for work to proceed, without the convening of an IBR. There are, however, significant questions regarding whether these cost/schedule accounts were established in a planned and controlled manner, a manner that ensured appropriate development of relationships between all WBS and OBS elements. These concerns notwithstanding, with the intent of this criterion being met by LM Aero actions and procedures warrants a *satisfactory* rating.

[17] An IBR is typically held within the early stages of a contract period of performance and it "establishes a mutual understanding of the project performance measurement baseline" and provides "an agreement on a plan of action to evaluate the risks inherent in the program measurement baseline and the management processes that operate during project execution." (DAG, 4.3.2.4.2)

[18] See Chapter IV, Section B for a discussion on delayed Spiral 2 IBRs.

***c. EVM Criterion #3: Provide for the integration of the company's planning, scheduling, budgeting, work authorization, and cost accumulation processes with each other, and, as appropriate, the program WBS and the program organizational structure.***

To ensure project goals are given priority over any one functional area's goals, the program must employ an integrated, single management control system using common information from the programs functional areas. The integration of master scheduling, cost estimating, work authorizations, budgeting and cost accumulation must work within a single database to ensure managers can get a complete picture of program health and make management decisions based on inputs from all functional disciplines.

The LM Aero defines an integrated process for developing project schedules and budgets, authorizing the work associated with those plans and accumulating and reporting costs and schedule progress consistent with the established WBS elements of the contract. During the development of the project schedule, activities are defined along with their interdependencies with other activities. These activities will become the basis for measuring performance in terms of resource requirements (i.e., cost to complete) and individual work package progress. Similarly, budgets are developed, authorized and accumulated by individual WBS elements (cost/schedule accounts), allowing measurement of program health at both the discreet work package level and "rolled up" higher WBS levels. This "rolling up" of program cost is accomplished mechanically and allows for flexible reporting of program status at varying project levels based on the desired focus.

The integration of the different functional areas of the Spiral 2 WBS and OBS was consistently observed. The development of the detailed Integrated Master Schedule (IMS), authorization of budget, and cost accumulation were all clearly tied to the program WBS. Additionally, organizational responsibility was clearly defined via the assignment of cost/schedule accounts to individual IPTs.

One concern, that will be addressed later, is the relationship between the project IMS and the detailed IPT activity schedules that supported the resource-loaded IMS. Specifically, the issue was how well they were linked and controlled. IMS and associated cost/schedule accounts were resource loaded and managed per defined work authorizations and performance measures. Lower tier IPT schedules developed to support the assigned activities were not directly linked to the IMS and, therefore, permitted IPTs to "interpret" their detailed schedules and take credit for progress against the IMS tasks. This approach is not consistent with the intent of this criterion which asserts the goal of measuring all progress against project goals versus individual IPT goals. This concern does not affect the intent of this criterion enough to warrant a negative assessment; therefore a *satisfactory* rating was given to this criterion.

### ***d. EVM Criterion #4: Identify the company organization or function responsible for controlling overhead (indirect costs).***

Adequate identification, allocation and tracking of program indirect costs is a concern for many programs. This is the first of four of the thirty-two EVM criteria that deal with management of indirect costs (others are Criteria #13, #19, and #24). Although not directly controlled by any individual project manager, indirect costs must still be clearly identified as a category, formally documented, and assigned to individual managers responsible for authorization and control.

Control of overhead rates and application to a specific LM Aero contract is the responsibility of the Overhead Section of the Aeronautics Controller. Surveillance of overhead costs allocated to the contract, however, is the responsibility of the project and functional managers.

Overhead rates applied to Spiral 2 contracts were used by LM Aero based on rates negotiated with Defense Contract Management Agency (DCMA). DCMA was also responsible to review performance reports to ensure rates were being applied in accordance with agreements. Although negotiation of each Spiral 2 contract focused on the applicability and appropriateness of applied overhead categories, once the negotiated indirect costs were authorized per the negotiated contract, the only control measure for the LM Aero and government program managers was a comparison of allocated overhead to the overhead portion of contract budget. LM Aero procedures and performance regarding the management of overhead indicated an *excellent* rating was appropriate for this criterion.

***e. EVM Criterion #5: Provide for integration of the program WBS and the program organizational structure in a manner that permits cost and schedule performance measurement by elements of either, or both, structures as needed.***

In order to measure performance, a standard must exist. This criterion concerns the formation of that standard, known within the military acquisition community as the program baseline. This concept has proven so important that three other criteria will deal with the issue of implementing a baseline.[19] This criterion concerns only the foundations of that baseline—that is, the integration of WBS and OBS.

According to LM Aero, management used IPTs to integrate Spiral 2's WBS and organizational structures. In general, IPTs had the responsibility of accomplishing tasks within specific CWBS elements. LM Aero allowed that, in general, an IPT may have more than one assigned CWBS element, but that IPTs did not share a single CWBS element. This assignment of a specific CWBS element to an IPT established the cost/schedule account, the base level of control which enabled future cost and schedule measurements.

The proof of these assertions lay in the fact that BCWS, BCWP, and ACWP were available at the cost/schedule account level. This data also was directly summarized to only one higher CWBS and only one IPT structure element in the CPR. Although the data was theoretically available for summarizing at any structure level, reports were only generated at the detail that LM Aero was contractually obligated to transmit. In the case of Spiral 2, the CDRL called for three reportable tiers within the CPR. In conclusion, with respect to LM Aero's actions concerning the integration of program WBS and OBS for the Spiral 2 program, the EVMS program warrants a *satisfactory* rating for meeting the letter of this criterion.

[19] ANSI/EIA EVMS Criteria #17, #18, and #25.

### 2. Group 2: Planning, Scheduling and Budgeting Criteria

Table 3 lists the assessments for each of the ten Planning, Scheduling and Budgeting Criteria in Group 2 of the ANSI/EIA EVMS Criteria.

| | Criteria | Assessment |
|---|---|---|
| 6 | Schedule the work | Marginal |
| 7 | Identify products, milestones and indicators | Satisfactory |
| 8 | Plan the Performance Measurement Baseline (PMB) | Marginal |
| 9 | Establish budgets for work | Inconclusive |
| 10 | Identify work packages | Satisfactory |
| 11 | Summarize work package budgets to control accounts | Satisfactory |
| 12 | Identify and control level of effort | Marginal |
| 13 | Establish overhead budgets | Satisfactory |
| 14 | Identify management reserves and undistributed budget. | Excellent |
| 15 | Summarize budgets to target cost | Excellent |

Table 3. Assessment of F-22 Spiral 2 Implementation of ANSI/EIA EVMS Planning, Scheduling and Budgeting Criteria

**a. *EVM Criterion #6: Schedule the authorized work in a manner that describes the sequence of work and identifies the significant task interdependencies required to meet the requirements of the program.***

When developing the IMS, a contractor must ensure that all activities required to complete the effort and the relationships between those activities are well defined. Many programs do not take the necessary steps to develop the IMS to the necessary level of detail. In order for EVM to be a useful management control tool, the IMS must be accurate with respect to allocation, consistency and traceability of budgeted schedule and resources.

For LM Aero the process of developing a project schedule begins with the Contract Delivery Schedule and ends with fully defined activity schedules. The factors affecting the scheduling process include required resources, available resources, span times, activity relationships and external constraints. As these factors are considered, activities are defined that produce necessary interim and final product(s) of the contract effort. As activities are defined and assigned to work packages (which are in turn assigned to a given cost/schedule account), schedule requirements are identified for each activity and resulting start/completion dates can be identified for a particular work package merely by identifying the start date for its earliest activity and the completion date for its final activity. The LM Aero process also highlights the critical and sometimes overlooked step of ensuring that interdependencies are clearly defined and understood for project work packages and their activities.

This is one of the criteria significantly impacted by the F-22 culture of changing requirements. While LM Aero took steps to build and manage to detailed and linked schedules, the frequent impacts of changing requirements made developing a baseline schedule very difficult. This culture of change resulted in Contract Delivery Schedules that did not provide confidence for the IPTs charged with developing the detailed work package activity schedules. All three Spiral 2 contracts were initiated and progressed several months (up to 50 percent of the contract period) prior to the establishment of a baselined IMS. This was especially troubling when considering the fact that exit criteria for the first two contracts included detailed IMS for their respective follow-on contracts.

The program recognized the need to have a detailed schedule prior to the initiation of a contract; however, the fluid requirements (as well as modernization program immaturity) made this unattainable for all three Spiral 2 contracts. As discussed above, once the detailed IMS was defined, it was noted in many cases there weren’t mechanical linkages between the IMS activities and the detailed activity schedules used by the IPTs. The approach used by LM Aero in the case of Spiral 2 was to define IMS activities by time span versus the detailed IPT tasks that would actually be required to be performed for completion of the respective activity. These shortcomings led to a *marginal* rating for this criterion associated with scheduling the work.

***b. EVM Criterion #7: Identify physical products, milestones, technical performance goals, or other indicators that will be used to measure progress.***

In order to take credit for earned value, a project must first identify the meaning of value. This criterion requires the contractor identify tangible measures for determining how much value has been earned in the progress of the effort. In the case of software development, where many interim products are difficult to measure, this is one of the more challenging criteria to meet.

LM Aero policy is lightly defined for this criterion. It does identify the requirement to objectively measure progress based on completion of tangible products, but it does not provide guidance on how to determine what is tangible. Their policy also states that “in most cases” progress will not be reflected for a particular activity until the activity has been assessed as complete (Lockheed Martin Aeronautics Corporation, 2005).

This criterion is one in which the authors have seen government customers lose confidence in contractor EVMS. The challenge is for the contractor and government to agree on the value of the products identified as program measures. Additionally, one could argue not all tangible products are necessarily measurable in terms of value—particularly in the case of software development. For example, when a lower tier IPT finishes coding a software product, how much value should be assigned to this product before it has been fully tested in an integrated fashion?

While many interfaces can be tested, most of the problems in software testing occur during integration testing versus unit testing. To give only minimal value to the product prior to integrated testing might undervalue the product and not accurately reflect the progress of the project. However, too many times a program takes too much credit for completion of the unit and later shows unfavorable variances when integrated testing identifies unplanned rework for the product.

Recognizing these challenges in Spiral 2, LM Aero attempted to assign values to the completed interim products based on the possibility (likelihood!) of problems with integrated testing that would require rework. The determination of how much value to assign to these interim products and how much budget to assign to integration test and rework activities was a process that required past experience. In this area LM Aero and their major supplier, Boeing, both had tremendous experience developing fighter aircraft; however, the new challenges of developing the first fully integrated avionics system combined with the years of software challenges seen in F-22 EMD, made this criterion one that required special focus from the government. LM Aero efforts to circumvent all of these challenges and adhere to their well-defined procedures in this area of identifying products, milestones and indicators yielded a *satisfactory* rating for this criterion.

***c. EVM Criterion #8: Establish and maintain a time-phased budget baseline at the control account level, against which program performance can be measured. Initial budgets established for performance will be based on either internal management goals or the external customer-negotiated target cost, including estimates for authorized but undefined work. Budget for far-term efforts may be held in higher-level accounts until an appropriate time for allocation at the control-account level. On government contracts, if an over-target baseline is used for performance measurement reporting purposes, prior notification must be provided to the customer.***

The “time-phased budget baseline” mentioned above describes the distinct EVM term known as Program Management Baseline (PMB).[20] The PMB must include all authorized work, and thus becomes beholden to the success of most of the previous criteria. Unless a given program has a well-defined PMB with effective management control systems in place, that program has little to no chance of providing useful insight regarding performance status using EVM data.

According to LM Aero, the PMB was established and maintained at the cost/schedule account level. For Spiral 2 the budget was based on the negotiated target cost, to include estimates for any contractually authorized but not negotiated changes (e.g., Undistributed Budget). The section of this criterion concerning reporting PMBs

[20] See discussion within the EVM Primer section of Chapter I.

reflecting an overrun (the "over-target baseline") was rendered non applicable due to the fact that Spiral 2 experienced an underrun. However, LM Aero communicated that before any of their projects can implement an over-target baseline for PMB purposes, the LM Aero F-22 program manager and Director of Cost Management Integration must justify and provide prior notification to the customer—the F-22 SPO.

Evaluating F-22 program implementation of this criterion necessitates dividing it into two parts: establishment and maintenance. The establishment half of this criterion warrants a *satisfactory* rating, given 1.) the establishment of the PMB within the Spiral 2 CPRs and Contract Funds Status Reports (CFSRs); 2.) the CPR and CFSR reconciliations with respect to authorized budgets; 3.) the CPR and CFSR reconciliations between the two reports themselves. The maintenance half of this criterion, much like Criterion #6, was significantly impacted by the F-22 culture of changing requirements. Specifically, late contract definitization (and subsequent IMS baselining) rendered the reported EVM data virtually useless.

As also described in Criterion #6, the approach used by LM Aero in the case of Spiral 2 was to define IMS activities by time span versus the detailed IPT tasks actually required to be performed for completion of the respective activity. Consequently, the final CPR reflected a PMB-derived EAC of $46M even while noting a "most likely" EAC of $24 million. Thus, up to the point of the final CPR submission on January 2005, all EVM data reflected performance based on a benchmark 192 percent more than the yet-to-be definitized EAC. As a result, the maintenance half of this criterion warrants an *insufficient* rating. In conclusion, with respect to Spiral 2 establishment and maintenance of a time-phased budget baseline at the control account level, the EVMS program warranted an overall *marginal* rating for meeting the purpose of this criterion.

***d. EVM Criterion #9: Establish budgets for authorized work with identification of significant cost elements (labor, material, and so on) as needed for internal management and for control of subcontractors.***

Criterion #9 pertains to total project budgeting, which a program can only accomplish through a comprehensive list of cost elements. As the above alludes to, effective formal control systems must accompany the roll-up of cost elements. Budgeted values must equate to negotiated project costs, from the standpoint of both supply (sub-contractors) and demand (F-22 SPO).

From LM Aero's perspective, work packages and planning packages were budgeted by elements of cost. Specifically, discrete portions of the total contract budget base were allocated to each Cost/Schedule Account Manager (C/SAM) through the Budget Ledger. LM Aero states that subcontracted CWBS elements were identified within the accounting system by "unique work orders and work-in-process subaccounts" (Lockheed Martin Aeronautics Corporation, 2005). Within the EVMS, these accounting system data items were represented by specific cost element codes. Once again, the use of a shared CWBS by all elements of the project organization assures a common understanding, consistency for planning and performance, and effective oversight of all contractually authorized tasks.

In practice, two issues surfaced regarding this criterion. First and foremost was a lack of verifiable supporting data. As explained within the preface of this chapter, the above paragraph describes policy as opposed to implementation. It should not, therefore, warrant consideration as proof positive of an effective execution of this criterion.

The second area of concern stemmed from the description of the Budget Ledger. According to LM Aero's own policy, the ledger may authorize the budget by CWBS element not only in terms of total dollars, but also in terms of less discrete cost elements such as labor hours/dollars and burden overhead dollars (to name a few examples). If the Budget Ledger described a C/SAM account's budget by cost element, responsibility laid with the IPT leader for translation of said cost element into total dollar terms. The resultant unclear "flexibility to budget the work packages/planning packages of the cost/schedule account in whatever mix of resources deemed appropriate" was seen as a material weakness with respect to this criterion (Lockheed Martin Aeronautics Corporation, 2005). However, that concern also lacked specific, verifiable supporting data. As such, with respect to Spiral 2 establishment of budgets for authorized work as needed for internal management and for control of subcontractors and maintenance of a time-phased budget baseline at the control account level, the EVMS program warranted an *inconclusive* rating due to lack of supporting data.

***e. EVM Criterion #10: To the extent that it is practical to identify the authorized work in discrete work packages, establish budgets for this work in terms of dollars, hours, or other measurable units. Where the entire control account is not subdivided into work packages, identify the far-term effort in larger planning packages for budget and scheduling purposes.***

This criterion further expands on Criterion #8, establishment of a definitive PMB, by identifying the need for discreetly defined work packages. Although "far-term" is not defined, it is recognized that at some point it becomes non-value-added to attempt discrete definition of work packages that are too far removed from the current state of the program. This criterion also identifies the requirement to establish measurable metrics for assessing the amount of work accomplished at any point in the effort.

LM Aero policy does not stipulate the delineation between near-term and far-term activities. It does, however, provide the planners more guidance than the ANSI/EIA criterion. While LM Aero directs that "all work [be] planned for the duration of the contract" (Lockheed Martin Aeronautics Corporation, 2005, p12), it also recognizes the lack of certainty or definition that may exist in activities planned outside of the current year of effort. The general approach is current year activities will be part of well-defined work packages while out year activities will be assigned to planning packages. It is important to note that while there exists less detail associated with the planning packages, they, like the work packages, are still defined with planned start/finish dates, quantity (units, hours, etc.) and dollars of resource required.

Due to the relatively short duration of all three Spiral 2 contract periods, LM Aero was able to develop discreetly defined work packages for the majority of the work performed on each effort. The first two contract efforts were each approximately one year in duration. The third was just over two years. The primary challenge of this criterion was the ability to define discreet work packages in an environment of changing requirements. With all three of these efforts proceeding under a UCA contract, there existed a lack of certainty regarding the content of the contract effort and contract funding. This led to more work than desired being held in either planning packages or undistributed budget (see Criterion #14). In conclusion, LM Aero implementation of this criterion, identifying the need for discreetly defined work packages, resulted in a *satisfactory* rating.

***f. EVM Criterion #11: Provide that the sum of all work-package budgets, plus planning-package budgets within the control account, equals the control-account budget.***

The sum of all Spiral 2 work and planning-package budgets should have been equal to their respective control account budgets. Furthermore, each of the control account budgets must have been related to a specific SOW. The only account that was not included was the Management Reserve (MR) account, held in general outside the purview of the performance baseline.

LM Aero acknowledged that distribution of Spiral 2-negotiated target cost was made from the individual cost/schedule accounts (aka control account) to their respective work and planning-packages. In all cases, LM Aero ensured that the sum of the budgets assigned to these packages equated to the total dollar budget authority of the cost/schedule account. Fulfillment of Criterion #1 made certain that each of the control account budgets related to a specific SOW.

The CPRs generated in support of Spiral 2 reporting substantiated LM Aero's policy regarding this criteria. An assessment of the data showed all work packages correctly summed up to their respective control accounts throughout the period of reporting (Apr 2004 through Jan 2005). MR grew during the reports, as expected given the at-the-time anticipated underrun. In conclusion, with respect to Spiral 2 summing of all budgets within a control account equating to the authorized total of that control account, the EVMS program warranted a *satisfactory* rating for meeting the purpose of this criterion.

***g. EVM Criterion #12: Identify and control level-of-effort (LOE) activity by time-phased budgets established for this purpose. Only that effort that is unmeasurable, or for which measurement is impractical, may be classified as LOE.***

LOE activities are of no benefit to a manager using EVMS because they measure the passage of time versus the accomplishment of tasks or delivery of products. While some activities clearly fall in the realm of LOE, minimizing the categorization of activities as LOE is necessary for a manager to accurately measure and manage his program's health.

LM Aero provides little guidance in the area of controlling LOE. They merely state that it "will exist only for those tasks where discreet or apportioned work measurement techniques cannot be effectively applied" and "will be separated from discreet and apportioned effort at the work package level" (Lockheed Martin Aeronautics Corporation, 2005).

This limited discussion of LOE and lack of specific guidance was apparent when assessing LM Aero's approach to applying LOE as a work measurement approach for Spiral 2 contracts. While it was expected that some efforts such as scheduling, configuration management and program management activities would naturally be associated with LOE, the use of LOE in Spiral 2 contracts did not appear to be in line with this criterion's goal of minimizing its use. One example was the use of LOE for some rework activities associated with the development of requirements and design documentation during the first two Spiral 2 contracts. Because of the difficulty of defining the activity associated with the rework of documentation during review cycles, LOE was used to capture this effort. This is just one example where LOE could have been better defined as discreet work, indicating that LM Aero could better focus their EVMS on minimizing LOE. Examples such as this led to a *marginal* rating for this criterion associated with control of LOE.

***h. EVM Criterion #13: Establish overhead budgets for each significant organizational component of the company for expenses that will become indirect costs. Reflect in the program budgets, at the appropriate level, the amounts in overhead pools that are planned to be allocated to the program as indirect costs.***

This criterion highlights concerns regarding the proper allocation of indirect costs to a project or program. To preclude manipulation a company must specify areas of indirect cost at program inception, with formal internal controls directing any subsequent changes. When indirect costs do not allocate directly to control accounts, the contracted organization should indicate some point within the WBS where the indirect costs apply.

LM Aero policy stipulated a formal, annual establishment of overhead budgets plant-wide. To start with, LM Aero forecasted both known and estimated business for their next fiscal cycle. This business included integration of the annual overhead budget with plans for contract performance, sales and profits, capital investments, and cash flow requirements. The Overhead Section of the Aeronautics Controller would then internally publish the indirect manpower and dollar targets necessary to support the assumptions used.[21] Following that, overhead budgets were established with functional organization development of internal assessments of requirements Targets were developed based on historical trends, current spending levels, expected or known changes in task/requirements and other quantitative or qualitative data and assigned based on the Aeronautics Controller Overhead Section's assessment.

Discrete items of cost were assigned to identified organizations for planning and control (starting with indirect manpower) and formally and discretely

[21] The assumptions used for overhead planning were not made available.

identified to the appropriate burden center/ overhead pool (see Figure 6 for a list of typically allocated overhead expenses; see Figure 7 for a generic example of how discrete expense accounts are allocated to overhead pools at LM Aero). Once approved, the budgeting system allowed for adjustments to the overhead budget due to anticipated changes in conditions and/or assumptions. Any overhead budget adjustments, however, required formal requests "from proper line management" (Lockheed Martin Aeronautics Corporation, 2005). Properly requested adjustments required detailed justification, which were evaluated by the Aeronautics Controller. LM Aero concluded with the statement that "appropriate line and company managers" must approve all upward adjustments (Lockheed Martin Aeronautics Corporation, 2005).

| **LM-Aero Overhead Accounts** |
|---|
| Salaries & Wages |
| Employee Awards |
| Group Insurance Program |
| Payroll Taxes & Insurance |
| Fringe Benefits |
| Retirement Plan |
| Savings Plan |
| Misc. Employee Benefits |
| Indirect Supplies & Material |
| Utilities |
| Depreciation & Amortization |
| Taxes |
| Travel & Communication Expense |
| Miscellaneous Expenses |
| Proposal & Bidding Expense |
| Independent Research & Development |
| Intercompany Expense |

Figure 6. Summary of Company Overhead Expense Accounts
(From: Lockheed Martin Aeronautics Company EVMS Description, 2005)

| OVERHEAD POOL (EXPENSE CODE) / ORGANIZATION | OCCUPANCY EXPENSE 000 | ADMINISTRATIVE SERVICE EXPENSE 400 | G & A EXPENSE 600 | ENGINEERING EXPENSE 700 | MAT'L PROCUREMENT EXPENSE 800 | MANUFACTURING EXPENSE 900 | FRINGE BENEFITS EXPENSE F00 | DOMESTIC MKTG EXPENSE D00 | FOREIGN MKTG EXPENSE G00 | G & A UNALLOWABLE EXPENSE U00 |
|---|---|---|---|---|---|---|---|---|---|---|
| VICE PRES. & GEN. MGR | | | X | | | | X | | | X |
| RESOURCES & SERVICES | X | X | X | X | | X | X | | | X |
| BUSINESS MANAGEMENT | | | X | X | | X | X | | | X |
| BUSINESS DEVELOPMENT | | | X | | | | X | X | X | X |
| COMPLIANCE AUDIT & VERIFICATION | | | X | | X | X | X | | | X |
| STRATEGIC PLANNING | | | X | | | | X | | | X |
| PROGRAM OFFICES (e.g., F-16, F-22, JSF, INFO. WARFARE) | | | X | X | | | X | | | X |
| ENGINEERING: | | | | | | | | | | |
| PRODUCT ENGINEERING | | | X | X | | | X | | | X |
| MFG. ENGINEERING | | | | | | X | X | | | X |
| OPERATIONS: | | | | | | | | | | |
| FABRICATION/TOOLING | | | | | | X | X | | | X |
| PRODUCTION/MATL/MRP | X | | X | X | X | X | X | | | X |
| OPERATIONS, F-16 PGMS | | | | | | X | X | | | X |
| QA /PROCESS QA | | | | | | X | X | | | X |
| PRODUCTION MGMT F-22 | | | | | | X | X | | | X |
| AERO MATL MGMT CTR | X | | X | | X | | X | | | X |

EXAMPLE

Figure 7. Overhead Pool Assignment for Organizational Expense
(From: Lockheed Martin Aeronautics Company EVMS Description, 2005)

In practice, the ability to manipulate indirect costs between profitable and less profitable programs creates a heightened concern to government procurement offices. The Company's annual publishing of its EVMS Description and Cost Accounting Standards created the expectation that LM Aero adhered to industry-acceptable methods of indirect cost allocation. Moreover, tracking and auditing for the allocation and accumulation of indirect costs against F-22 contracts was managed by DCMA located in the LM Aero facilities in Fort Worth, Texas. DCMA is responsible for negotiating and monitoring overhead rates for all LM Aero contract efforts based in Fort Worth, including Spiral 2 software development. Additionally, they received and monitored all EVMS reports for the Spiral 2 effort, and identified no negative findings or inconsistencies with how LM Aero allocated, accumulated or reported indirect costs on the Spiral 2 contracts. As such, with respect to Spiral 2's allocation of indirect costs towards authorized budget, the EVMS program warranted a *satisfactory* rating for meeting the purpose of this criterion.

***i. EVM Criterion #14: Identify management reserves and undistributed budget.***

Identifying and controlling both management reserve (MR) and undistributed budget (UB) is necessary to maintain the integrity of a program's EVMS. MR, used to cover the cost of "unknowns", must be held outside the PMB and will not be assigned to a WBS element until a decision is made by management to do so. UB, part of the project PMB, represents funds that have been identified as essential for completion of the project, but have yet to be assigned to a WBS element.

While LM Aero policy leaves it to the discretion of the program manager whether MR is required for a project, it is clear in directing that MR and UB be maintained separate from the PMB. Further, it clearly stipulates that all transactions with respect to MR and UB will be documented.

All three Spiral 2 contracts had both MR and UB clearly identified at the IBRs. With all three efforts being initiated as UCAs there was UB for all three contracts. Once the efforts were negotiated, the UB was appropriately distributed to the applicable WBS elements. The assessment for this criterion associated with MR and UB was determined to be *excellent*.

***j. EVM Criterion #15: Provide that the program target cost goal is reconciled with the sum of all internal program budgets and management reserves.***

This criterion concentrates on the accountability of all project funds. As a result, a contractor must strive to keep its total project costs within their authorized budgets. Along those same lines, the contractor must exhibit documented control processes to ensure that total project costs are kept in check.

LM Aero's response to this criterion meets expectations. The negotiated contract target cost was distributed to the control accounts—$36M total. The total target cost ($46M) also included UB ($5M) and MR ($5M). Therefore, the amount distributed to the control accounts, plus the value of UB and MR, reconciled to the contract's total target cost.

Today's cost tracking software makes it difficult—if not impossible—to fail in observing this criterion. When the F-22 SPO received CPRs from LM Aero electronically, the CPRs were accompanied with software packets that ported directly into a program made expressly for tracking EV data. Therefore, should any portion of program costs not equate to the total, the software identified and isolated the cost(s) in question. This made reconciliation more of a technical issue rather than an analytical one—in most cases. In conclusion, with respect to Spiral 2's reconciliation of all internal program budgets (plus reserves) the EVMS program warranted an *excellent* rating for meeting and exceeding the purpose of this criterion.

### 3. Group 3: Accounting Criteria

Table 4 identifies the assessments provided to each of the six ANSI/EIA EVMS Accounting Criteria.

| | **Criteria** | **Assessment** |
|---|---|---|
| 16 | Record direct costs | Excellent |
| 17 | Summarize direct cost to the WBS | Satisfactory |
| 18 | Summarize direct cost to the organization | Marginal |
| 19 | Record indirect costs | Excellent |
| 20 | Identify unit/lot costs | Inconclusive |
| 21 | Record material costs | Inconclusive |

Table 4. Assessment of F-22 Spiral 2 Implementation of ANSI/EIA EVMS Accounting Criteria

***a. EVM Criterion #16: Record direct costs in a manner consistent with the budgets in a formal system controlled by the general books of account.***

According to Fleming and Koppelman (2000, p171), the preferred method for recording direct costs is "applied direct method", accounting for resources as they are used or consumed. In labor intensive efforts such as software development, where teams are typically established by functional disciplines, the challenge is to ensure direct labor costs are appropriately charged to the correct project with many.

LM Aero policy provides great detail regarding the cost identification and numbering systems, work order nomenclature, direct charge policies, work-in-process (WIP) subaccounts, recurring vs. nonrecurring costs, and the direct labor charge/accounting process. LM Aero uses the applied direct method, based on the procedures outlined in LM Aero policy.

Although not unique to F-22 Spiral 2 software development (or even to software development in general), the government has always had concerns in the area of cost accounting and how charges are tracked to different work packages. With managers or IPTs having more than one charge account at their disposal, on any given day, what prevents an individual or IPT from charging to a "healthy" account versus the one they are working on that is near or at an over-run state? Although this is not addressed in LM Aero policy, the government must continue to rely on the power of audits, DCMA, and LM Aero adherence to generally accepted accounting standards. The detail provided by LM Aero procedures along with observed implementation warranted an *excellent* rating for this criterion associated with recording direct costs.

***b. EVM Criterion #17: When a WBS is used, summarize direct costs from control accounts in the WBS without allocation of a single control account to two or more WBS elements.***

The purpose of this criterion: to eliminate the confusion resulting from multiple WBS elements crisscrossed with multiple control accounts. A WBS element by its nature identifies a unique control account, which eliminates the possibility of dividing a control account between multiple WBS elements. Additionally, the WBS design ensures that a lower level element uniquely identifies with one (and only one) higher level element or tier.

The LM Aero F-22 team strived to meet this criterion via its basic accounting numbering system. An eight character work order forms the foundation of the system. Spiral 2 work orders, through their unique eight characters, recorded and identified incurred costs to the contract, then to the contract line item, followed by work breakdown structure elements, and finally to the discrete tasks within the WBS elements. Work order numbers were established by the Accounting Department within the terms of the Spiral 2 contract modifications to the REDI contract. A record of all authorized work orders was maintained by the Accounting Department, while active work orders were maintained in a computer file which was readily accessible by company personnel.

In practice, LM Aero identified the first three characters of the work order as representing the contract code number assigned to the contract. With respect to Spiral 2, this code was shared with all REDI contract actions and subsequent modifications. The second grouping of the work order (characters four and five), also known as the project code, aligned costs with CWBS elements. The third and final grouping of the work order (characters six through eight), also known as the job code, provided detail within the project by identifying costs along with their respective job or specific task item. With respect to Spiral 2's WBS utilization and respective control accounts related to one and only one given WBS, the EVMS program warranted a *satisfactory* rating for meeting the purpose of this criterion.

***c. EVM Criterion #18: Summarize direct costs from the control accounts in the contractor's organizational elements without allocation of a single control account to two or more organizational elements.***

This criterion builds on Criterion #2 which identified the need for assigning each element of the WBS to an organization. Criterion #18 requires a contractor's cost accounting system be capable of collecting, summing and reporting cost accounts by functional organizations (e.g., engineering, quality, production, etc.). This provides managers an ability to measure the work being accomplished by functional area as a program progresses. This criterion also explicitly stipulates what is inferred in Criterion #2—that a single control account may not be assigned more than one functional organization.

As with most of today's contractors, LM Aero does most of their development activities through multi-functional IPTs. Although this criterion appears to call for breaking cost/schedule account work packages apart based on functional organizations, LM Aero policy does not take this approach. In order to ensure the ability to summarize costs by functional organizations, LM Aero developed an employee numbering approach that identifies each employee by their functional area regardless of what organization to which they are assigned. Since employees record their hours in a work package using their employee number, a summary of labor costs can be accomplished by functional area.

Spiral 2 used many functional disciplines during its development. The ability to identify/summarize effort by functional organization was never observed by the government. Although LM Aero policy identifies this as a capability, reports showing this capability were never produced. Government requests for these reports were never supported leaving questions regarding LM Aero's ability to meet this criterion. Based on the data provided, however, there was enough concern to warrant a *marginal* rating for this criterion.

#### ***d. EVM Criterion #19: Record all indirect costs that will be allocated to the contract.***

EVM Criterion #19 is related to the functional responsibility for controlling indirect costs of Criterion #4. This criterion, however, goes further in requiring that the contractor be able to identify indirect costs at the point charged, summarize them, and relate them to original planned budgets. It also requires the relationship be formally documented between those controlling indirect costs and those able to incur costs against indirect budgets. Whatever method is chosen by the contractor to allocate indirect costs, it must be documented, consistently applied and auditable.

LM Aero policy regarding the allocation and accumulation is consistent with generally accepted accounting procedures and uses a monthly adjusted year-to-date approach that is intended to minimize year-end adjustments. Additionally, the policy identifies the requirement to accumulate indirect costs both by expense account and organizational department, consistent with this and other criteria.

Tracking and auditing for the allocation and accumulation of indirect costs against F-22 contracts is managed by DCMA located in the LM Aero facilities in Fort Worth, Texas. DCMA is responsible for negotiating and monitoring overhead rates for all LM Aero contract efforts based in Fort Worth, including Spiral 2 software development. Additionally, they received and monitored all EVMS reports for the Spiral 2 effort, and identified no negative findings or inconsistencies with how LM Aero allocated, accumulated or reported indirect costs on the Spiral 2 contracts.

#### *e. EVM Criterion #20: Identify unit costs, equivalent unit costs, or lot costs when needed.*

The focus of this criterion is the establishment of unit, lot, and recurring costs for use in future efforts. In order to accomplish this, the contractor must be able to distinguish, in cost accounts, the differences between recurring (e.g., production) and non-recurring (e.g., development) activities.

LM Aero cost accounting does not support the tracking of direct unit or lot costs. The method used to obtain these values is an annual calculation of average unit cost for the specified WBS elements. Segregation of recurring and non-recurring, LM Aero establishes discreet work accounts that are defined based on recurring or non-recurring activities. The charges associated with these efforts can be summarized through the WBS as with other work activities.

Spiral 2 software development for the F-22 was almost exclusively a non-recurring effort. All “production” of Spiral 2 software was non-recurring and the installation of the finished software to aircraft was accomplished via separate production contracts (or modifications). While there were opportunities to apply lessons learned to follow-on F-22 development activities, these could not be considered recurring as they involved different requirements, schedules and teams. Based on the lack of applicability to Spiral 2, this criterion was assessed as *inconclusive*.

***f. EVM Criterion #21: For EVMS, the material accounting system will provide for:***

***1. Accurate cost accumulation and assignment of costs to control accounts in a manner consistent with the budgets using recognized, acceptable, costing techniques.***

***2. Cost performance measurement at the point in time most suitable for the category of material involved, but no earlier than the time of progress payments or actual receipt of material.***

***3. Full accountability of all material purchased for the program including the residual inventory.***

This criterion ensures useful measurements of cost and schedule variance (CV and SV) related to the material accounting system. It requires allocation of all appropriate purchases to the same accounting period, thus reflecting planned versus earned value (proper recording enables an accurate SV). This same expected allocation process also aids in the proper accounting of earned versus actual costs (proper recording enables an accurate CV).

LM Aero provided a detailed (but general) description of the company's in-place processes that deal directly with this criterion. LM Aero's Accounting division established routines that ensured the validity of the data input (used for tracking cost accumulation) while enabling any necessary editing for "transactional existence and compatibility" (Lockheed Martin Aeronautics Company, 2005). These same routines also helped maintain appropriate records: specifically, those records dealing with requirements, commitments, receipts, issues, and inventory by group, part number, unit, and actual price. The accounting records also enabled identification of different groups or cost types, which in turn permitted summarization of costs into basic categories such as raw materials, hardware, equipment, tooling materials, and purchased parts. Finally, the accounting records also allowed for subcontract and inter-company work transfers identification. The description then began an overview of direct charge materials (procurements), work-in-process accounting, and (contract) inventories:

- Upon receipt, raw materials, hardware, equipment, tooling material, and purchased parts, along with major component/subsystem procurements, were charged to the Spiral 2-specific contract work order. Materials-related items such as tooling and shipping (i.e., other than manufacturing materials) were reported against the gaining control accounts at issue from inventory.

- Sub-accounts identified as work-in-process (WIP) provided the status of a given item in the process flow (e.g., on dock, in inventory, or placed into production). WIP-related progress payments were segregated into separate WIP-inventory accounts—under the buying contract—for unique cost identification. Upon receipt of the procured item, the subcontractor's progress payments were liquidated and the value was recorded to the appropriate WIP account.

- Contract inventories were carried at purchase order price. Source documents from these contract inventories were utilized to collect charges for input to the cost accumulation system (from receiving reports, invoices, requisitions, etc). From that point, costs were accrued for unbilled received items and unmatched invoice suspense items, such as those related to subsystem vendors and subcontractors. These accruals were distributed to the appropriate contract work orders and work-in-process sub-accounts each month.

In practice, incurred or accrued costs for direct charge materials and major components/subsystems procurement were reported against the benefiting control accounts upon issue from inventory for performance measurement purposes. The study failed to acquire information regarding LM Aero’s material accounting system as it pertained directly to Spiral 2. LM Aero policy meets the guidelines of this criterion. The apparent lack of visibility, however, into the Spiral 2-specific material accounting system coupled with LM Aero's vague, unbilled items policies and unmatched invoices made an unchallenged acceptance of criterion satisfaction with respect to Spiral 2 difficult. With respect to Spiral 2 existence within LM Aero's material accounting system, the EVMS program warranted an *inconclusive* rating due to lack of Spiral 2-specific supporting data.

### 4. Group 4: Analysis Criteria

Table 5 lists the assessments determined for each of the six ANSI/EIA EVMS Analysis Criteria.

| | Criteria | Assessment |
|---|---|---|
| 22 | Identify schedule and cost variances | Satisfactory |
| 23 | Analyze schedule and cost variances | Satisfactory |
| 24 | Analyze indirect costs | Satisfactory |
| 25 | Summarize data elements and variances for reporting | Satisfactory |
| 26 | Implement managerial actions | Insufficient |
| 27 | Develop revised estimates of cost at completion | Marginal |

Table 5. Assessment of F-22 Spiral 2 Implementation of ANSI/EIA EVMS Analysis Criteria

***a. EVM Criterion #22: At least on a monthly basis, generate the following information at the control account and other levels, as necessary for management control, using actual cost data from, or reconcilable with, the accounting system:***

***1. Comparison of the amount of planned budget and the amount of budget earned for work accomplished. This comparison provides the SV.***

***2. Comparison of the amount of budget earned and the actual (applied where appropriate) direct costs for the same work. This comparison provides the CV.***

This criterion forms the foundation of EVM reporting. Its focus is to compare performance at the control account level with earned value results. Compliance with this criterion should translate into program managers identifying potential overruns and underruns.

LM Aero stated that BCWS, BCWP and ACWP were identified for each control account monthly. The Accounting Department's Cost Ledger provided the ACWP for each control account. BCWS values were generated from work packages according to the PMB, and summarized to the control accounts for each respective cost element. Budgetary values for cost elements reported as earned (for completed work packages) and completed portions of in-process work packages resulted in the BCWP. For work packages that utilized other-than-cost work measurement systems, target values (e.g., standard hours) assigned to activities were earned as activities completed. Comparing the cumulative earned targets against the total target value for each performing department, the work package percent completion status is determined and used to calculate BCWP for the work package.[22] BCWP for special cases was calculated as follows:

- Work packages established for tooling and manufacturing materials and work packages established for procured tools earned their budgetary dollar value incrementally as these materials or tools were issued for processing and/or use.

- The cost of any subcontracted items/systems issued was recorded to specific accounting WIP sub-accounts by work order. Cumulative actual costs against these sub-accounts were compared to the total estimate for these subcontracted items/systems to determine a percent completion then used in calculating a subcontractor BCWP. Budgets for the nonrecurring effort of major subcontractors were time-phased within work packages according to the planned receipt and payment of each vendor's invoice: when the invoice was allocated to WIP, earned value (BCWP) was awarded.

- Major subcontractors classified as critical subcontractors (e.g., Boeing, Northrop-Grumman) and under contract for other than a firm fixed price

[22] For many discretely measured work packages, the timing and amount of the budgetary value earned depends upon activity completion. As an activity completes, BCWP was earned for the work package in the proportion of the activity's resource estimate (relative to the total resource estimate of the work package).

were contractually obligated to comply with additional control and reporting criteria. For example, status reporting in compliance with ANSI EVMS Criteria provided an additional cost and schedule performance measurement tool. This data became the source of any reported performance related to the subcontractor.

In practice, as stated within the description of this criterion, performance data was essential at the control account level since it effectively enabled monitoring of project performance. For a project like Spiral 2 that was organized according to an IPT structure, the performance data provided the program manager with a summary of progress and cost performance on each WBS element assigned to the Spiral 2 team. Spiral 2 data generated at month-end began reflecting a favorable performance variance, confirming the underrun anticipated due to the over-estimated undefinitized contract much of Spiral 2 existed under. During the Spiral 2 Phase B CPR reporting period (April 2004 through January 2005), the F-22 SPO had no outstanding issues regarding the figures generated for BCWS, BCWP, ACWP, CV, and SV, and LM Aero consistently and reliably reported them every month during the contract duration.[23] In conclusion, with respect to Spiral 2's generation of BCWS, BCWP, ACWP, CV, and SV on at least a monthly basis, the EVMS program warranted a *satisfactory* rating for meeting the purpose of this criterion.

***b. EVM Criterion #23: Identify, at least monthly, the significant differences between both planned and actual schedule performance and planned and actual cost performance, and provide the reasons for the variances in the detail needed by program management.***

This criterion asserts that whenever either SV or CV reported from a given CPR exceeds a previously agreed-upon level between customer and contractor, the contractor should analyze associated drivers and provide a reason why that threshold was

[23] This criterion does not consider the disconnect between undefinitized and definitized contract costs: rather, it only looks for the successful generation of the EVM measures listed.

broken. This arrangement should also filter down to major-subcontractors. Additionally, a plan for recovery is considered customary alongside a given variance analysis.

LM Aero stated that contract significant variances were determined by the variance reporting conditions negotiated for the CPR. Whenever a WBS summary level element's variance satisfied the conditions negotiated for CPR analysis (i.e., negatively surpassed the contracted threshold), the company documented an analysis of variances for those control accounts principally responsible for the summary level variance, and inserted a variance package within that period’s CPR (if the customer contracted for it). Reasons for significant progress differences from the plan were also identified.

The CPRs related to Spiral 2 Phase B reflected adherence to this criterion. When Spiral 2 Phase B was contracted, the F-22 Program Office identified the CPR Format 5 (Variance Analysis) as necessary for effective program oversight. Every month LM Aero was contractually required to report variance analysis. Beginning with the October 2004 CPR, LM Aero reported significantly positive CVs, indicating the already-anticipated underrun derived from definitization of the project at a much lower target cost. In conclusion, with respect to Spiral 2’s identification of significant CV and SV on at least a monthly basis, the EVMS program warranted a *satisfactory* rating for meeting the purpose of this criterion.

***c. EVM Criterion #24: Identify budgeted and applied (or actual) indirect costs at the level and frequency needed by management for effective control, along with the reasons for any significant variances.***

Changes in indirect costs can be an important consideration of the project management. An increase in indirect charges is driven by either an increase in the indirect expenses of the project or a decrease in the direct base over which the indirect charges are applied. This criterion requires that changes against the baseline for indirect charges be identified and adverse impacts be addressed.

The identification of variances between indirect budget and actual indirect charges is evaluated on a monthly basis by each LM Aero department head.

Additionally, indirect manpower actuals are collected on a weekly basis and variances are reported to upper management.

Although the F-22 Program Office was never able to obtain detailed indirect charges associated with modernization contracts, DCMA who is responsible for monitoring all indirect charges per negotiated rates never identified any finding or concerns for the Spiral 2 delivery orders. Based on this absence of negative findings an assessment of *satisfactory* was provided for meeting the purpose of this criterion.

***d. EVM Criterion #25: Summarize the data elements and associated variances through the program organization and/or WBS to support management needs and any customer reporting specified in the contract.***

This criterion acknowledges control account-level variances are not reported simply because they either offset themselves (a negative and a positive) and/or the contractor can (and prefers to) handle such management details in-house. However, any project must have flexibility in reporting variances. Furthermore, internal and external reports must align.

LM Aero stated that performance data was summarized from the control accounts through the WBS. Also, data from one control account was allocated only to its unique summary-level WBS element. BCWS, BCWP, ACWP, SV, and CV were summarized directly to the reporting level specified within the contract in question.

Once again, the CPRs related to Spiral 2 Phase B reflected adherence to this criterion. When Spiral 2 Phase B was contracted, the SPO-side of the F-22 program identified the CPR Formats 1 (WBS), 2 (IPT Structure), and 5 (Variance Analysis) as necessary for effective program oversight through the Spiral 2 Phase B-associated CDRL. Thus, every month LM Aero was contractually required to report data elements and variance analysis within the parameters of these formats. In conclusion, with respect to Spiral 2 summarization of data elements (and associated variances) through the program organization and/or WBS that supported management and customer needs, the EVMS program warranted a *satisfactory* rating for meeting the purpose of this criterion.

***e. EVM Criterion #26: Implement managerial actions taken as the result of EV information.***

The intent of this criterion is to ensure specific procedures and policies are set in place to ensure management identifies corrective actions whenever EV variances indicate either poor performance (i.e., negative variances) or a faulty baseline plan (i.e., positive variances). Thresholds must be identified in advance to trigger management involvement. These thresholds must be meaningful, should be at multiple monitoring points, and be in terms of both positive and negative variances.

LM Aero considers the requirement of this criterion to be synonymous with Criterion #22, generation of monthly reports identifying schedule and cost variances. The identification of predefined variance thresholds are negotiated for each contract LM Aero enters with the government. According to LM Aero procedures, once these thresholds are breached, actions must be taken to both identify the reason for significant variances and identify the managerial corrective action.

When looking at Spiral 2 DO 0002, the only stand-alone Spiral 2 contract complete to date, compliance with this criterion was suspect. Although variance thresholds were identified (monthly: $1M and +/- 10%; cumulative: $2M and +/- 10%) there was no evidence that these thresholds meant anything. Throughout the entire effort DO 0002 showed significant positive cost variances. Five of the ten months of EV reporting had cost variances greater than the $1M threshold set by the contract. This indicated a questionable contract baseline. Although various root causes were discussed for the significant variances, no steps were taken to rebaseline the program to a more realistic plan. At its completion, DO-0002 completed approximately 40 percent under its UCA value, clearly indicating the PMB managed to during the execution of the contract was not an accurate reflection of contract costs. In conclusion, the assessment for the F-22 EVMS implementation of the criterion associated with taking necessary managerial actions was *insufficient*.

***f. EVM Criterion #27 – Develop revised estimates of cost at completion based on performance to date, commitment values for material, and estimates for future conditions. Compare this information with the PMB to identify variances at completion important to company management and any applicable customer-reporting requirements, including statements of funding requirements.***

This criterion deals with the EVM summary of data elements known as EAC.[24] Routine calculation of EAC must ensure both accuracy and timeliness, as transgression of either brings the entire cost of the project into uncertainty. The final step is to routinely compare the EAC with the PMB to ascertain the progress, or lack thereof, of the program in question.

LM Aero policy required performing comprehensive updates of cost-to-complete at least twice a year, and more frequently if directed. The initial step in preparing an estimate of cost-at-completion was ensuring all authorized tasks were aligned with both their appropriate WBS element(s) and their respective departments (those expected to perform the tasks). Estimated completion dates were reviewed and revised as appropriate, with consideration given to performance to date, and authorized tasks not yet defined and planned as specific activities were forecast within undefined aggregates. Notable within cost-to-complete forecasts (due to management and customer interest) were direct labor and overhead rates. The direct labor rates included projections made from extrapolations of rates-to-date, labor union agreements, company merit assumptions, changes projected in level of employment, and skill mixes required to complete the remaining work. Cost-to-complete overhead rates were expressed as applied overhead rates and forward pricing rates. They were normally revised annually (or more frequently) based on actual and projected business conditions. Once initial calculation of cost-to-complete was finished, the project team determined the project's cost-to-complete iteratively via process of estimation, review, feedback, and revision.

[24] See discussion within the EVM Primer section of Chapter I.

The CPRs related to Spiral 2 Phase B reflected adherence to the development of revised estimates portion of this criterion. CPR Formats 1 and 2 highlighted Latest Revised Estimates (LREs) as the project went on, showing a slight positive CV until the final report (January 2005) formally acknowledged the definitized contract price via the Management EAC block in Format 1. It is assumed this late acknowledgement of such a significant variance was forced due to attempted adherence to a somewhat-conflicting Criterion #30. The revised estimates provided little to no management control given the magnitude of the contract price change, and thus at least partly failed to meet the comparison portion of this criterion. The fact that useful, formal information was not reported until the final CPR validated that statement. In conclusion, with respect to Spiral 2 development of revised estimates of cost at completion based on performance to date, commitment values for material, and estimates for future conditions, the EVMS program warranted a *marginal* rating for exhibiting some material failures in meeting the purpose of this criterion.

### 5. Revisions Criteria

Table 6 identifies the assessment for each of the five criteria under the ANSI/EIA EVMS Revisions Criteria.

| | Criteria | Assessment |
|---|---|---|
| 28 | Incorporate changes into plans, budgets and schedules | Satisfactory |
| 29 | Reconcile budgets changes | Inconclusive |
| 30 | Control retroactive changes | Excellent |
| 31 | Control revisions to the program budget | Excellent |
| 32 | Document changes to the PMB | Satisfactory |

Table 6. Assessment of F-22 Spiral 2 Implementation of ANSI/EIA EVMS Revisions Criteria

***a. EVM Criterion #28: Incorporate authorized changes in a timely manner, recording the effects of such changes in budgets and schedules. In the directed effort prior to negotiation of change, base such revisions on the amount estimated and budgeted to the program organizations.***

Although "timely" is not defined, it is reasonable to expect any contractor and government team should be able to agree on what constitutes a "timely" update to project plans to incorporate necessary changes. Changes may be driven either internally (e.g., significant cost or schedule overruns) or externally (e.g., changes in contract scope or available funding). Regardless of the cause, the owners of the PMB must be able to update the plan and incorporate the necessary changes in a short enough time to minimize lack of useful EV data.

The LM Aero policy governing this criterion stipulates the contract budget base will be updated following contractual authorization. Although no specific timeline can be provided for the various contract modifications that could occur, the policy states that "generally within 60 days after contractual authorization the change will be incorporated into program schedules and the performance measurement baseline" (Lockheed Martin Aeronautics Corporation, 2005). Although the policy addresses changes driven by contract (external) changes, there is no discussion or direction regarding the need to rebaseline the PMB due to internal project execution issues. This is addressed in Criterion #32.

Rebaselining of schedules and PMB has been a challenge for the F-22 since the earliest days of the program. Based on F-22 records, the entire development program underwent annual rebaselining the first three years of the program. This set the tone for the remainder of the EMD phase of the program and continued into the post-EMD modernization development efforts such as Spiral 2. According to interviews with Spiral 2 managers, the approach regarding Spiral 2 was to use "rolling baselines" to accommodate constantly changing schedules, requirements and external perturbations. While these frequent changes to the baseline may be occurring in a "timely" manner, the intent of this criterion is not to merely update the PMB. It is to accurately and realistically update the PMB so that frequent updates of the program plan are not required. The challenge for the Spiral 2 management team was discerning when PMB rebaselines were being driven by external factors versus poor performance against the baseline. The concerns associated with this criterion were not driven by the Spiral 2 implementation of the criterion as much as with the factors that contributed to the frequent rebaselining; therefore, a rating of *satisfactory* was warranted for this criterion.

#### ***b. EVM Criterion #29: Reconcile current budgets to prior budgets, in terms of changes to the authorized work and internal replanning in the detail needed by management for effective control.***

This criterion highlights the importance of traceability with respect to WBS, specifically changes affecting the baseline. Program teams need to provide this traceability to the lowest level, given that baselines are generally developed with a bottoms-up method. That traceability provides the means for reconciliation between current and prior budgets.

LM Aero asserts that any of their programs' contract budget bases and/or PMBs will change only as a result of negotiations that result in contractual change authorizations or revisions to proposal values. (PMBs can also change as a result of approved internal replanning). LM Aero identifies each contractual change and reconciles it to the original contract budget base and/or PMB. This ensures target cost integrity reporting both internally and to its customers.

The short duration of Spiral 2 DO 0002 appeared to negate any opportunity that might have provided proof of adherence to this criterion. By January 2005, when the change to the total contract budget was formally recognized, $22M of the revised contract total of $24M had already been accomplished. Thus, per the Spiral 2 DO 0002 CDRL, with over 95 percent of the work accomplished, CPRs were no longer required.[25] The study failed to acquire information regarding LM Aero's traceability of budget changes as it pertained directly to Spiral 2. Though LM Aero policy met the

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[25] $22M was 95 percent of the non-award fee total of the definitized contract budget base.

guidelines of this criterion, the apparent lack of visibility into Spiral 2-specific budgetary changes made an unchallenged acceptance of criterion satisfaction with respect to Spiral 2 alone difficult. As such, with respect to Spiral 2's ability to reconcile budgetary changes, the EVMS program warranted an *inconclusive* rating due to lack of Spiral 2-specific supporting data.

***c. EVM Criterion #30: Control retroactive changes to records pertaining to work performed that would change previously reported amounts for actual costs, EV, or budgets. Adjustments should be made only for correction of errors, routine accounting adjustments, effects of customer- or management-directed changes, or to improve the baseline integrity and accuracy of performance measurement data.***

The intent of this criterion is to ensure the integrity of the EVMS. If budgets or actuals are changed after-the-fact, the usefulness of the EVMS as a management control tool is lost. The only appropriate retroactive updates are those made to correct errors or other legitimate accounting adjustments.

It was not surprising to find LM Aero policy specifically prohibits changes to previously reported actual costs unless it is done as a correction of errors or an accounting adjustment. Even then, the policy stipulates any changes to previously reported EV data must be coordinated through and approved by senior management.

Inappropriate changes to reported data would be a serious infraction of contractual obligations and a breach of trust. There has never been an indication through audits or otherwise that LM Aero would jeopardize their relationship with the government or their EVMS certification to retroactively change EV data. As such an *excellent* rating was warranted for this criterion.

***d. EVM Criterion #31 – Prevent revisions to the program budget, except for authorized changes.***

Virtually all DoD programs experience challenges to the plan originally put forward at the beginning of the effort. Sometimes these challenges become so severe that project managers need to change the budget baseline to a more realistic budget baseline. This criterion recognizes baselines may change, but any changes to the budget associated with the baseline must be changed on a limited basis and in a controlled environment.

In the case of LM Aero, EVMS policy states that a contract budget base can only be changed when authorized through a proposal update. This policy ensures the contractor will never unilaterally change the budget baseline. Based on this strong policy and observed performance in this area, an *excellent* rating was warranted for this criterion.

#### *e. EVM Criterion #32: Document changes to the PMB.*

As changes occur to the project PMB, these changes must be controlled and traceable. Unauthorized changes to the PMB undermine the utility of the EVMS. Similarly, when an update to the baseline cannot be traced to the original plan, it becomes difficult to identify where trade-offs occurred, impacts to other areas of the program, or simply program history.

Under Criterion #10, LM Aero typical policy is to define detailed work packages for all efforts within the current contract year. Budgets for activities planned beyond the current year, particularly those in support of development efforts, are held in planning packages until more is known regarding the activity's details. As the project progresses and these planning packages are transitioned into detailed work packages, these changes are captured in documentation, showing the relationships between the planning packages and work packages. Additionally, changes driven by external program pressures, as discussed in Criterion #28, are to be documented and identify linkages to the previous PMB.

As discussed in Criterion #28, the Spiral 2 PMB was updated using "rolling baselines" to accommodate for external perturbations. Unfortunately, while these changing baselines showed linkages to previous PMB, where possible, many times the changes to the PMB were significant enough that traceability between activities became very difficult. Additionally, it was difficult to identify which changes occurred in the PMB as a result of external pressures versus poor internal performance. The inability of project managers to identify these differences limits the utility of the EV data. These concerns notwithstanding, the F-22 documentation of changes to the PMB was assessed to be sufficiently in keeping with the criterion, warranting a *satisfactory* rating.

## C. SUMMARY

Table 7 summarizes the authors' assessments of how each of the 32 ANSI/EVMS criteria was applied on F-22 Spiral 2. While there were several criteria not met (or which lacked the requisite verification), there was not a systemic failure in the EVMS process at F-22. Rather, most of the challenges being faced by the use of EVMS on Spiral 2 were driven by issues outside of the EVMS spectrum. This will be further discussed in Chapter IV, *F-22 EVMS Environment*, where the F-22 development environment may have contributed to difficulties in EVMS implementation.

| | Criteria | Assessment |
|---|---|---|
| **Group 1: Organization** | | |
| 1 | Define authorized work (WBS elements) | Satisfactory |
| 2 | Identify organizational responsibilities | Satisfactory |
| 3 | Integrate the system | Satisfactory |
| 4 | Identify overhead management | Excellent |
| 5 | Provide for performance measurement | Satisfactory |
| **Group 2: Planning, Scheduling and Budgeting** | | |
| 6 | Schedule the work | Marginal |
| 7 | Identify products, milestones and indicators | Satisfactory |
| 8 | Plan the Performance Measurement Baseline (PMB) | Marginal |
| 9 | Establish budgets for work | Inconclusive |
| 10 | Identify work packages | Satisfactory |
| 11 | Summarize work package budgets to control accounts | Satisfactory |
| 12 | Identify and control level of effort | Marginal |
| 13 | Establish overhead budgets | Satisfactory |
| 14 | Identify management reserves and undistributed budget. | Excellent |
| 15 | Summarize budgets to target cost | Excellent |
| **Group 3: Accounting** | | |
| 16 | Record direct costs | Excellent |
| 17 | Summarize direct cost to the WBS | Satisfactory |
| 18 | Summarize direct cost to the organization | Marginal |
| 19 | Record indirect costs | Excellent |
| 20 | Identify unit/lot costs | Inconclusive |
| 21 | Record material costs | Inconclusive |
| **Group 4: Analysis** | | |
| 22 | Identify schedule and cost variances | Satisfactory |
| 23 | Analyze schedule and cost variances | Satisfactory |
| 24 | Analyze indirect costs | Satisfactory |
| 25 | Summarize data elements and variances for reporting | Satisfactory |
| 26 | Implement managerial actions | Insufficient |
| 27 | Develop revised estimates of cost at completion | Marginal |
| **Group 5: Revisions** | | |
| 28 | Incorporate changes into plans, budgets and schedules | Satisfactory |
| 29 | Reconcile budgets changes | Inconclusive |
| 30 | Control retroactive changes | Excellent |
| 31 | Control revisions to the program budget | Excellent |
| 32 | Document changes to the PMB | Satisfactory |

Table 7. Assessment of F-22 Spiral 2 Implementation of ANSI/EIA EVMS Criteria

# IV. F-22 EVMS ENVIRONMENT

## A. PREFACE

While the previous chapter sought to answer if the F-22 EVMS was implemented per industry standards established for specifically that purpose, this chapter examines if the F-22 EVMS fulfills its role as a management control system for the avionics software development program in question and if F-22 managers used EVM products to manage the avionics development effort. In answering each of these questions, however, it was important to consider the environment within which the F-22 EVMS was employed. During the course of gathering data, collecting questionnaire responses, and discussing the use of EVM with F-22 managers, the authors identified certain foundational elements necessary for successful implementation of EVM not addressed by the 32 ANSI/EIA EVMS criteria. These are foundational issues behind any successful development program regardless of EVM use; however, many of these are often cited as the challenges facing today's DoD software development efforts. Examples include requirements stability, schedule stability, funding stability and a realistic PMB. In the first section of this chapter three limiting factors or *barriers* were examined for their impact on the success of EVMS implementation in the F-22 Spiral 2 program. Next, the question "To what degree did the F-22 Spiral 2 implementation of EVM fulfill its role as a management control system for avionics software development?" was addressed by looking at CPRs for the avionics development program. Finally, if EVMS is to be valuable to managers, they must have confidence in the tool and be knowledgeable about EVM and the data being generated. The final section of this chapter reports the analysis of the questionnaire provided to Spiral 2 government and contractor personnel and intended to address this question.

## B. EVMS BARRIERS IN THE F-22 PROGRAM

### 1. Undefinitized Contracts

As discussed in Chapter II, *Literature Review*, at the end of EMD the F-22 program recognized the challenges faced during EMD needed to be addressed in the modernization program to prevent a repeat of cost overruns, schedule delays and undelivered performance. One of the approaches implemented to address the fluid requirements, constantly changing funding levels and technological challenges was the method of contracting for each incremental ("Spiral") product delivery via phased contracts.

Figure 8, Spiral 2 Summary Schedule, shows how each of these contracts was phased with respect to each other during the development of Spiral 2. The approach of having multiple contract phases for each spiral provided the desired programmatic flexibility; however, there was a cost to the business side of the program. With more contracts in work than ever before and the remaining issue of consistent changes in program baselines, the award of negotiated, definitized contracts became unattainable.

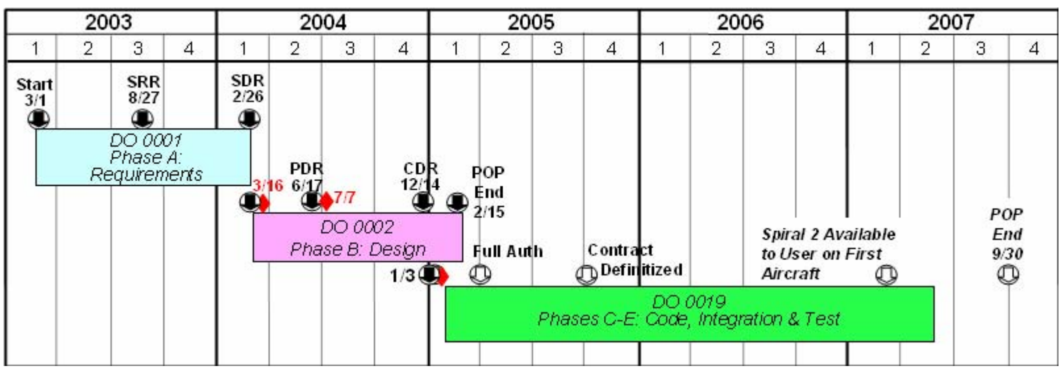


Figure 8. Spiral 2 Summary Schedule
(From: DO 0019 Integrated Baseline Review)

By the time Spiral 2 was initiated in 2003, the F-22 program frequently used UCAs in initiating new efforts with LM Aero. The complexities of the modernization program, with multiple increments at various stages all dealing with funding perturbations and requirement/technology iterations, made modernization even more susceptible to UCAs. Not an anomaly as much as the norm, Spiral 2 had all three of its development contracts initiated under UCAs. In fact, LM Aero completed the first two phases of the Spiral 2 program before the respective contracts were definitized.[26] Considering the undefinitized nature of UCAs,[27] the use of EVM was extremely difficult, if not impossible.

As discussed in the previous chapter, the second group of criteria deals with planning, scheduling and budgeting the program. If a program was initiated under a UCA, many times it was due to the immaturity of the program plan. Sometimes this was due to lack of understanding of the effort At times it was due to an inability to define this knowledge in terms of a negotiated definitive contract. Most times, as was the case with Spiral 2, it was a mixture of both.

In some cases the scope of the work awarded under the UCA was defined so immaturely, it was impractical to hold an IBR early enough in the contract to capture a significant portion of the work to be performed. DO 0019 was an example of this with work being initiated on this effort in January 2005 under a limited UCA and the IBR being accomplished in January 2006. Clearly EVMS has limited value in instances such as these where an IBR can not be held to establish the baseline. When one year of effort (out of a total of three) was accomplished before an IBR was held, it severely limited the manager's ability to measure progress against a program baseline.

In the case of DO 0002, a program baseline was established via an IBR while under a UCA; however, there were significant limitations to the value of PMB established at this IBR. These limitations were driven by several factors, including:

- A lack of confidence in the final contract value
- Lack of buy-in between the parties on required tasks to complete the work (i.e., contract scope)

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26 Recall from Chapter II the first phase of Spiral 2, requirements analysis, was actually accomplished under REDI DO 0001, the overarching modernization program's systems engineering and program management effort. This DO, initiated in January 2003 via a UCA, was not definitized until after Spiral 2 scope was completed in March 2004. DO 0002, detailed design, was awarded via a UCA in March 2004 and was also definitized well after task completion in February 2005. DO 0019, awarded as a UCA in February 2005, was definitized in October 2005.

27 Typically, UCA's are based on not-to-exceed (NTE) values without much, if any, supporting data.

- The inability of the contractor to fully assign dollars to all Cost Account Managers (CAM).

Regardless of whether an IBR was held and a program baseline established none of the PMB was likely to be contractual under a UCA. This resulted in difficulty for the government in controlling changes to the baseline during the execution of the UCA, or when the contract was later definitized.

Spiral 2 DO 0002, detailed design, was an example of this challenge. Originally awarded as a UCA based on an NTE, DO 0002 IBR was accomplished less than 90 days after UCA award; however, with so much of the effort based on NTE values, it was difficult for government managers to assess the validity of the PMB during the IBR. Ultimately, DO 0002 would be completed under a UCA and was definitized after completion of work for 42 percent less dollars than originally contracted under the UCA. With this much of a difference between the work projected and the work performed, EVM was difficult to use as a management control tool. As the contractor team constantly ran below budget for the effort, government managers were always faced with the question of determining how much of the underrun was due to efficient performance versus excessive budget.[28] This lack of confidence in the PMB significantly reduced its value as a management tool.

### 2. Requirements Instability

Requirements instability is one of the most commonly cited problems with suffering software development programs. With its changing mission, the F-22 was especially susceptible to changing requirements during the early stages of Spiral 2. While any large DoD weapon system program will be challenged with shifting requirements (called "creep"), the addition of the air-to-ground capabilities to the existing

[28] At the end of DO 0002, LM Aero was commended for aggressively implementing process improvements that enabled increased performance and criticized (in award fee and past performance documentation) for excessive cost estimating. One of the responses LM Aero provided to this critique was that the DO 0002 excessive underrun was more due to changing requirements than poor budgeting. The following section looks at Spiral 2 requirements stability.

air-to-air mission of the F-22 presented especially challenging pressures on the modernization program to incorporate capabilities that had not been planned for the fighter. In addition to the changing mission of the program, the senior managers of F-22 were fighting to retain the program funds as DoD sought dollars to pay for Global War on Terror operations. This resulted in capabilities being promised to senior DoD leadership and congress prior to any evaluations of the impact of incorporation into the subject Spiral. Although the Spiral development model was established to maximize the program's ability to adjust requirements as required, it was never intended to facilitate the frequent changes in requirements that Spiral 2 experienced.

As requirements analysis neared completion in January 2004, the requirements baseline was established for detailed design. This set of requirements was the basis for the DO 0002 UCA. In March 2004, shortly after DO 0002 was authorized, the first letter was written to LM Aero changing the major capabilities being developed for Spiral 2. In the summer of 2004, funding constraints and external political pressures forced the program to formally direct requirement changes to LM Aero four times between July and September. This instability in core Spiral 2 requirements, made the use of a PMB for DO 0002 almost impossible. Every iteration of requirements changes led to a major rebaseline of the program plan. This, coupled with the cultural effect of knowing requirement changes were always being considered, led to lack of confidence in the PMB and, therefore, the EVM data on which it was based. Operating in this environment of constantly changing baselines yielded what was commonly referred to as "rolling baselines."[29] Rolling baselines were key indicators of the lack of program stability. Whether the instability was internal or external, the impact was the same: loss of confidence in EVM. Although the EVM process is designed with the intent of absorbing changes to the program baseline, when a program makes changes to its baseline as frequently as the F-22 Spiral 2 program did, the value provided by EVM begins to deteriorate as confidence is lost in the existing baseline.

[29] Similar to (and often a result of) requirements creep, this nomenclature describes a flexible baseline that lacks the stability essential for benchmarking performance measurements.

An additional problem with frequent rebaselines was the increased difficulty in identifying the history of the PMB updates. While the last five of the 32 ANSI/EIA EVMS criteria specifically address the need to control changes in PMB and other EVM baselines, the more frequently changes occurred, the more difficult it became to identify the relationships between current and former baselines. As changes continued to be made to the program baseline, whether in scope, resources, or schedule, it became more difficult to trace the relationship between the original baseline and its EAC and the current baseline and its EAC. This was critical for a program constantly being pressured to justify funding and provide measures of remaining effort.

### 3. Timeliness of EVM Reports

The EVM reporting cycle required in all Spiral 2 contracts was monthly. While Criteria #22 and #23 identify a minimum EVM reporting cycle of one month, most of the F-22 government users identified this reporting cycle as being insufficient to enable use of EVM as a management tool. LM Aero management and IPT leads had access to preliminary EVM data on at least a weekly basis; however, unless government managers established a trusting relationship with their LM Aero counterparts, they did not see any of this data until the formal EVM reports were delivered four to six weeks after the work was completed.

The primary driver for this delay is the necessity of LM Aero to complete their monthly cost accounting before developing and delivering reports. If formal reports were provided to the government prior to the end of the accounting period changes may have been required at the end of the period. While many in the government would likely understand this situation and trade it for the ability to see the data earlier, it does expose LM Aero and the program leadership to potential problems if they make decisions based on preliminary data. Additionally, as changes occurred at the end of the accounting periods, there might be many who would lose confidence in the accuracy of the preliminary data.

Based on discussions with F-22 government managers, it was determined the desired approach was to establish a trusting relationship with the contractor manager to gain as much access as possible to preliminary EVM data. This enabled access to timely, if not completely accurate, data that supported management making decisions. Still this was an informal agreement and was completely based on the “good will” of the LM Aero manager. It also limited government managers in their ability to report emerging issues up their management chain. The first reason for this was because it was based on preliminary data that could change. The second concern was that it would “spoil” the relationship with the contractor manager who would be less likely to provide access to preliminary EVM data.

## C. SPIRAL 2 EVMS DATA ANALYSIS

This section primarily addressed the second question posed within *Methodology*, Chapter I: “To what degree did the F-22 Spiral 2 implementation of EVM fulfill its role as a management control system for avionics software development?” To help answer the question, Cost Performance Reports (CPRs) directly related to Spiral 2 efforts were distilled into raw cost and schedule measurements. Then a Spiral 2 DO 0002 lifecycle EVM analysis was accomplished and compared to outputs from LM Aero reports. The comparison, in addition to the EVM data elements’ results and pertinent testimony from individuals involved, answered the question.

In order to collect the data necessary, CPRs from the REDI contract modification known as Spiral 2 DO 0002 were gathered, the complete set dating from April 2004 through January 2005. Using the raw numbers from the Format 2 reports, an Excel spreadsheet was created that took the lowest level IPT EVM data elements, summed them up through the IPT levels (as opposed to inputting data from the CPRs’ higher level IPTs), and generated trend lines for EVM data element analysis (e.g., BCWS, BCWP, ACWP, etc.). Please refer to Appendix I for the complete set of monthly reports.

### 1. CPR and Independent Analysis Comparison

Beginning with the first CPR (April 2005), an interesting disconnect appeared between SV and CV. SV results put the program behind schedule by $31,000, while CV exhibited a cost underrun of $660,000—45 percent of the BCWP for that period. Conventional wisdom normally leads to the conclusion that behind schedule equates to a cost underrun, but usually at a somewhat similar measurement (e.g., SV = 10, CV = 12). A twenty-one-fold increase from SV to CV indicated either one of two conclusions, or some combination of both: efficiencies were occurring within one or more IPTs, or the original budget assumptions were grossly incorrect. Regardless, the EVM data was highlighting an area of concern for program management.

Subsequent reports only heightened that concern. By midway through the CPR reporting cycle (August 2004), the CV indicated a $4.9M underrun—56 percent of the ACWP cumulative-to-date—while SV indicated a less unwieldy $63,000 behind schedule. That said, LM Aero's Format 5 (Variance Analysis) for that period stated, "There [were] no current period, cumulative-to-date or at-completion variances which exceed[ed] thresholds in [August 2005]'s report." Thus, even though the EVM data was indicating an area of concern regarding Spiral 2 DO 0002 performance, LM Aero's analysis reports to the F-22 SPO indicated all EVM data elements were within tolerances. Not until the October 2004 report did LM Aero's formal Variance Analysis begin to offer a reason behind the recurring, outsized CVs.

In a similar case, this study's independent EVM analysis uncovered an area of concern regarding the CPR reports' data summarization. In the June 2004 report, the independent analysis revealed a relatively minor anomaly in reporting that continued into the final report (January 2005). Whereas the CPR in question reported BCWS cumulative-to-date as $6.775M for the entire program, the independent analysis reported the same data element as $6.863M, resulting in a delta of $88,000. Though small in relative size, this anomalous delta effected an investigation into the cause. The investigation found that when the May 2004 CPR's BCWS cumulative-to-date ($4.437M) was added to the June 2004 CPR's BCWS current period ($2.428M), the result netted a $6.865M amount that should have corresponded to June 2004 BCWS cumulative-to-date. Note this figure results in a minor $2,000 delta between the independent analysis' same figures (easily explained by rounding error). As already disclosed, this error continued through subsequent CPRs, ranging in value from $82,000 to $134,000.

Successive study netted a similar anomaly. Beginning with the June 2004 CPR report, the independent analysis reported the BCWP cumulative-to-date data element as $6.694M; when compared to the actual CPR's corresponding value of $6.562M, this resulted in a delta of $132,000. Again, the investigation found when the May 2004 CPR's BCWP cumulative-to-date ($4.570M) was added to the June 2004 CPR's BCWS current period ($2.127M), the result netted a $6.697M amount that should have corresponded to June 2004 BCWS cumulative-to-date. Note that this figure results in a minor $3,000 delta between the independent analysis' same figures (easily explained by rounding error). Like before, this phenomenon continued throughout the remaining CPRs, ranging in value from $114,000 to $166,000.

In both BCWP and BCWS cases, the Mission Sys & SW (Avionics Systems Engineering Integration Team and Mission Avionics Software) and Modernization IPTs were the cost drivers for all affected CPRs. Investigation revealed the "What?" portion of the cause, but failed to uncover the "Why." These inexplicable errors raise concerns regarding the validity and veracity of the reports given to the government.

### 2. EVM Trend Analysis

This study's trend analysis benefited from hindsight. Given the facts known after the program concluded, the Spiral 2 DO 0002 program was clearly overestimated, a fact unknown to management until the effort was completed in early 2005. In theory, the EVM data elements should have reflected that fact. The following results—acquired from the independent EVM analysis—exhibited trends that supported, at least in part, the conclusion that the data elements did forewarn of problems related to program budget assumptions, which in turn translated to a probable exaggeration of BCWS and BCWP.

A top line analysis of current-period EVM data elements revealed that whatever the budget assumptions were that comprised the Spiral 2 DO 0002 undefinitized contract baseline, the work continued closely to plan throughout much of the program. The BCWS, BCWP, and SV lines in Figure 9 clearly denoted this. The figure also clearly indicated real costs lagged budgeted for all but one period of the program via the ACWP line (below both BCWS and BCWP) and resultant CV line (positive for all but one reporting period). These results lead to the conclusion that budgeted costs (represented by BCWS and BCWP) were overestimated relative to actual costs (i.e., ACWP).

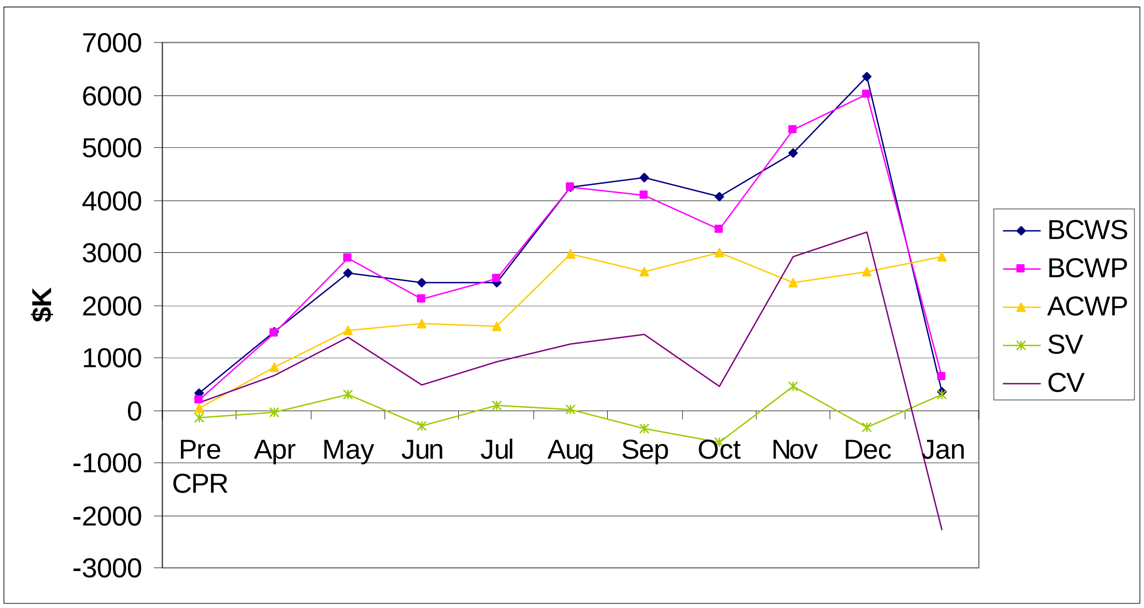


Figure 9. F-22 Modernization REDI DO0002 Data Elements (Current)

A top line analysis of cumulative EVM data elements supported the preceding conclusion (see Figure 10). Throughout the lifecycle of the program, BCWS and BCWP remained similar while ACWP lagged both. As a result, SV remained relatively flat and CV grew. These results lead to the conclusion that budgeted costs (represented by BCWS and BCWP) were overestimated relative to actual costs (i.e., ACWP).

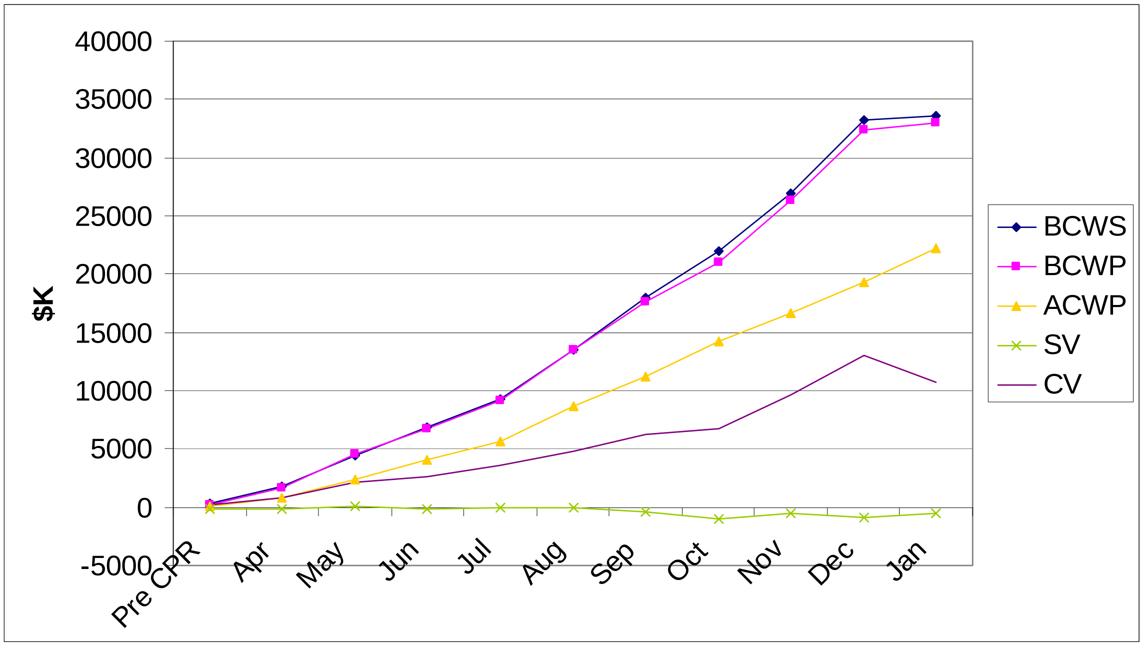

Figure 10. F-22 Modernization REDI DO0002 Data Elements (Cumulative)

The general question of whether EVM identified a disconnect between program budgeted costs and actual costs answered, did EVM identify any other leading indicators warranting management's attention? To answer that question, the independent analysis looked at each EVM data element in terms of IPT totals (see Figures 11 and 12). As expected, the totals supported the suspicion of incorrect budgetary estimates. They also lead to the conclusion that much of the blame for the high CV lay with Mission Sys & SW. This particular IPT contributed the majority of cost to every data element analyzed. Knowing that, program management, theoretically, could have focused management control efforts on work occurring within that IPT. More to the point, the data provided by EVM indicated program instabilities in addition to identifying areas of the program which warranted closer attention.

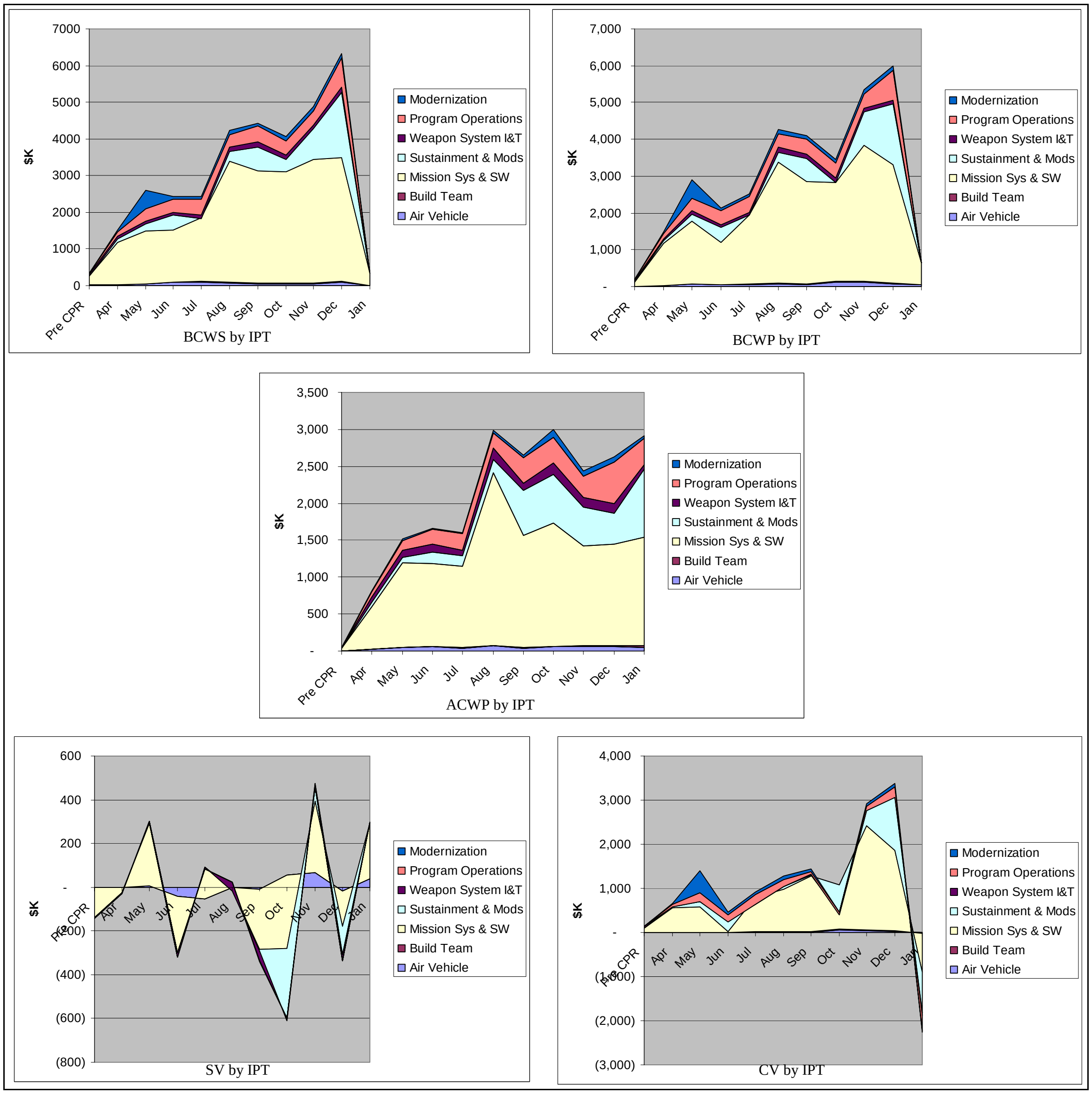


Figure 11. F-22 Modernization Spiral 2 DO 0002 Data Elements Summed by IPT (Current Period)

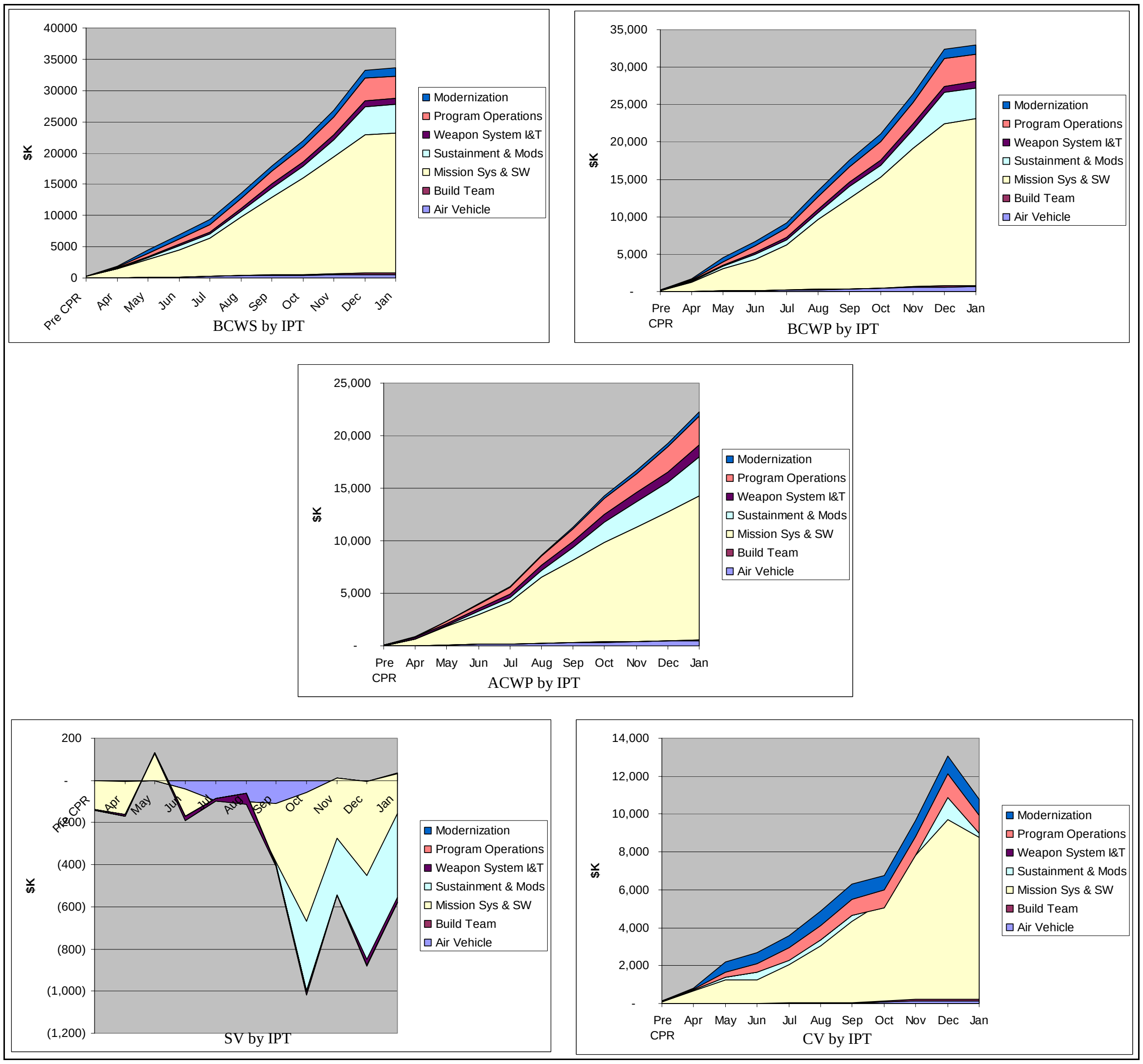


Figure 12. F-22 Modernization Spiral 2 DO 0002 Data Elements Summed by IPT (Cumulative-to-Date)

## D. QUESTIONNAIRE ANALYSIS

This section addresses the final question posed in this paper, "To what extent did the F-22 program management (Government and Contractor) use EVM products to manage avionics development efforts?" The method chosen to address this question was the use of a questionnaire. Following is an overview of the questionnaire and an analysis of the responses.

### 1. Questionnaire Overview

The questionnaire (see Appendix II) aimed to assess the perceived usefulness of EVM within a software development context. The questionnaire consisted of nine closed-ended questions falling into three distinct areas. The first area (Questions #1 and #2) focused on the respondent's background by asking them to categorize themselves by government or contractor function(s) and area(s) of focus within F-22 development. The second area (Questions #3 and #4) of the questionnaire sought to establish the respondent's level of interaction with EVM by looking for their frequency and method of use. The final area (Questions #5 through #9) built on the respondent's interaction with EVM and sought their assessment of EVM. Questions in this area focused on the respondent's perceived value and usefulness of F-22 EVMS and its data as well as a self-assessment of their knowledge of EVM and the 32 ANSI/EIA criteria. Those identifying themselves as being aware of the 32 ANSI/EIA criteria were asked to assess the F-22 implementation of EVM with respect to these 32 criteria.

The questionnaire was provided to a mix of 26 government and contractor F-22 personnel. They included program managers, engineers, contracting officers, and financial managers who worked on the F-22 program. All government and contractor personnel directly managing Spiral 2 development were provided the questionnaire and responded. Additionally, other F-22 government managers not directly supporting Spiral 2 or modernization were asked to respond to the questionnaire. All government personnel who were provided the questionnaire were assigned to the F-22 System Program Office (SPO).

### 2. Summary of Responses

There were 25 responses to the questionnaire from both government and contractor F-22 personnel.[30] Seventeen (68 percent) of the respondents were government SPO personnel. Although these 17 respondents only represent approximately 9 percent of the personnel assigned to the F-22 program office at the time of the study[31], they accounted for 100 percent of government personnel assigned to the Spiral 2 program. Additionally, all eight contractor respondents were Spiral 2 personnel. While the sample for the questionnaire was well-below a meaningful representation for the entire F-22 program, it was a very good representation for the Spiral 2 program. Additionally, when looking at the area of the program supported by the respondents, 22 of the 25 responses (88 percent) were from personnel who support the modernization program. Because of the functional matrix organizational approach used by the F-22 program, it was difficult to determine the total number of personnel working on the modernization program; however, it was strongly believed by the authors that these 22 individuals represented a statistically significant number of modernization personnel.

Figure 13 shows how the respondents' support of program areas and elements was distributed for government and contractor personnel. When categorizing the program element(s) on which the respondents worked there was a majority of respondents who supported avionics. Because personnel support multiple areas and elements of the program, respondents were permitted to select more than one functional area and program element.

[30] One response was deemed invalid due to incomplete answers.

[31] Based on F-22 System Program Office headcount of 194 active duty military and DoD civilians provided in telephone interview with front office personnel on 13 November 2006.

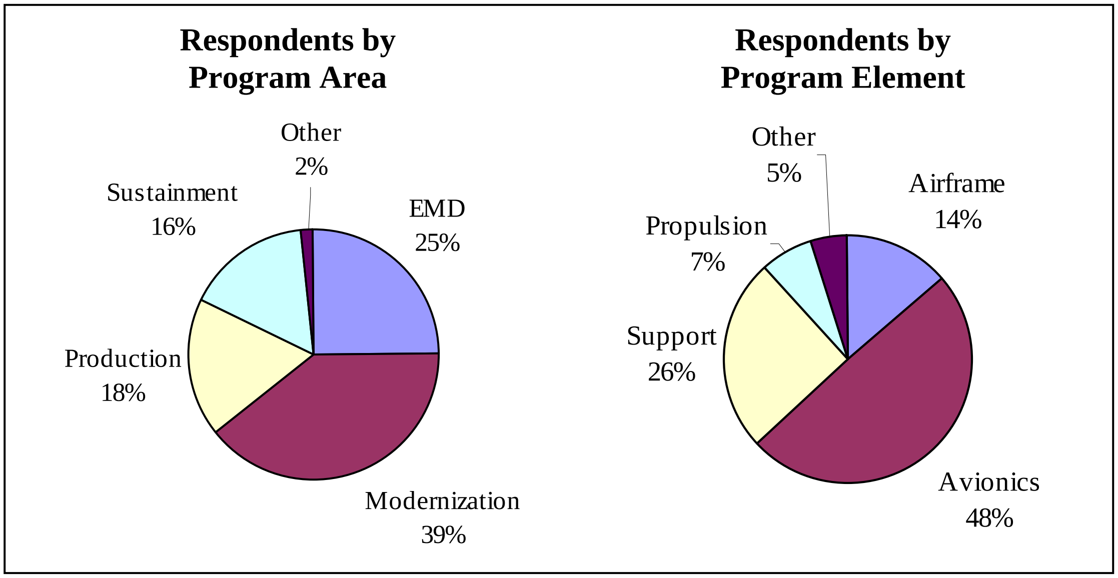


Figure 13. Distribution of Respondents

When looking at some of the specific responses from the questionnaire, there were definite trends in some areas. Some of the most notable of these were with respect to the 32 ANSI/EIA criteria. Nineteen (76 percent) of the respondents stated they were not aware of the 32 criteria. Considering the importance of these criteria in determining whether an EVMS has been correctly implemented, it was surprising to see how many users were unaware of the criteria. Perhaps this was why EVM could have been implemented on Spiral 2 and had as many criteria be judged as *marginal* in their implementation. Another interesting trend with respect to the 32 criteria was, of the six respondents who said they were aware of the 32 criteria, all stated they believed EVM was being implemented on F-22 in compliance with these criteria. The binary (Yes/No) response to the question “Do you think your program implements its EVMS according to the 32 ANSI/EIA-748 Earned Value Management System criteria?” may have forced some respondents to go with the “predominate” response—after all, the question didn’t ask if their program EVMS *meets all* of the 32 criteria. It was still surprising for the authors to see 100 percent of these respondents respond in the affirmative to this question considering the authors’ findings on the criteria were not unanimous.

Additional trends were observed with respect to contractor versus government responses. The most notable was the increased frequency of EVM use on the part of contractor respondents versus government respondents (see Figure 14). Of the 17 government personnel who stated some use of EVM, 15 (88 percent) of the respondents stated they used EVM less than once per week, while two stated they used it once per week. Contrasting this to the seven (87.5 percent) of the eight contractor respondents who all stated they used EVM at least once per week. Of these seven, two (25 percent) of the contractors stated they used EVM more than once per week. This disparity in frequency of use was not a surprise to the authors based on the concern raised by government personnel regarding the timeliness of EVM data. As discussed above, while contractor managers have access to preliminary EVM data less than one week old, the government only receives EVM data once it is provided in formal reports that are weeks later than the work being reported. This disparity in timeliness is the most likely driver for the disparity in frequency of use between the two organizations.

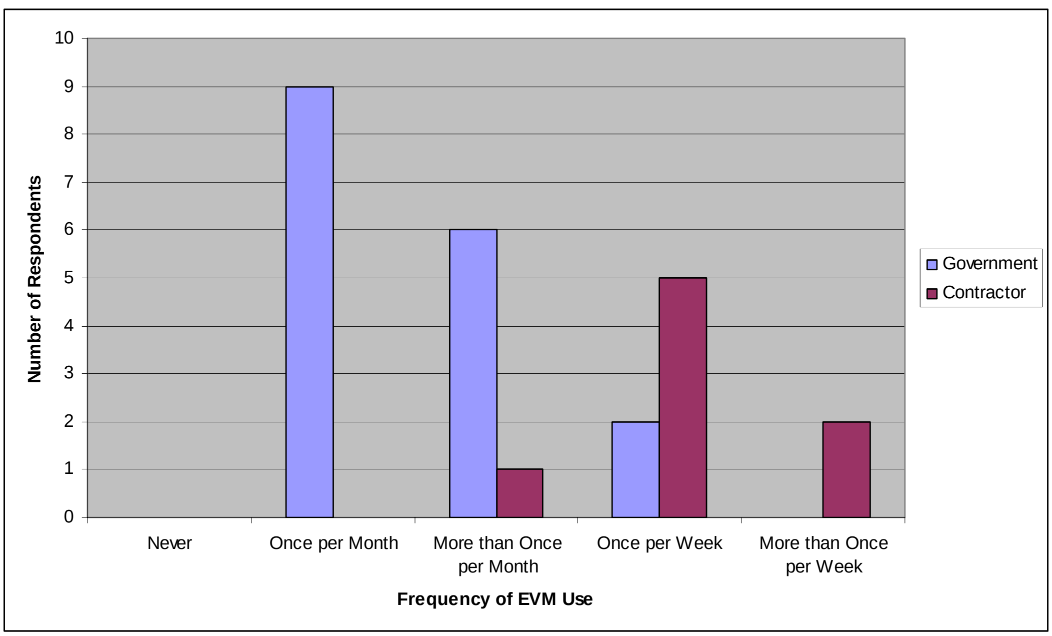


Figure 14. Frequency of EVM Use by Government and Contractor Respondents

### 3. Propositions

The process of evaluating the responses to the questionnaires resulted in several propositions, each of which enabled further analysis of potential relationships and trends regarding EVMS usage and perceived value. Each of these propositions was evaluated individually using questionnaire responses to determine their validity. Although the results of the analysis of propositions are presented below, more detailed supporting data and values for the questionnaire responses and analysis is provided in Appendix III.

#### *a. Higher EVM Value Results in More EVM Usage*

The first proposition was that an individual who places higher value on EVMS as a management tool will use EVMS more frequently. Of the 25 respondents, 17 (68 percent) stated they viewed EVMS as having moderate or lower value (three or less on a scale of one to five). Meanwhile, there were 16 (64 percent) respondents who stated they used EVMS more than once per month. When testing the relationship between these two variables, there was not enough statistical evidence to accept this proposition with 95 percent certainty. However, there was enough of a relationship between these variables to state that, having 90 percent certainty, the more value an individual placed on EVMS, the more they used the tool.

This proposition, supported by the questionnaire results[32], provided some measure of confidence in the validity of the questionnaire. It would have been counter-intuitive for there to not have been a relationship between perceived value and frequency of use. Any tool that is truly believed to be valuable should be used more often.

#### *b. Higher EVM Usefulness Results in More Usage of EVM in Managing*

The second proposition was that individuals who had an opinion of higher usefulness for EVMS would use it more as a management tool versus just a reporting

[32] Per statistical analysis, propositions are either "rejected" or "not rejected." Failure to reject a proposition does not necessarily make it "true." For simplicity, the authors refer to propositions that were "not rejected" as being true.

tool. Although EVMS is intended to be used as a management tool, 11 (44 percent) of the F-22 respondents either solely or predominately used EVMS to receive and report cost and schedule status. Twelve (48 percent) of the respondents stated they used EVM data either equally as a management and reporting tool or predominately as a management tool.[33] As discussed above, many times the timeliness of the EVM reports limited the utility of EVM as a management tool. This proposition sought to identify any linkage between respondents' perceived usefulness and more meaningful usage of the data. This proposition was also supported by the responses with 90 percent certainty.

The difficulty in interpreting this proposition was which variable was the driver. That is, did method of use drive perceived value (i.e., a management tool is likely to be deemed more "useful" than a reporting tool) or did perceived usefulness drive method of use (i.e., a meaningful source of data will be used for managing instead of merely reporting)? This question could not be answered by the data collected in the questionnaire; however, it was important enough merely to confirm there was a linkage between these two responses. Regardless of the driver, the relationship existed in the questionnaire responses and pointed to the important—perhaps essential!—linkage between the two variables.

#### *c. Higher EVM Knowledge Results in Higher EVM Value*

The final proposition was that individuals who identified themselves as having more knowledge regarding EVM would place a higher value on EVM. The rationale behind this proposition was that individuals who knew more about the data and application of EVM would place more value on its ability to be used as a management tool. Based on the results of the questionnaire, however, this was not the case. Regardless of the level of certainty, there was nothing in the results to support this proposition. This indicated respondents determine their value in EVMS via other means. One likely source would be their own "return" on using the EVM products. This is just one potential driver and the question of where the value was derived was not specifically

[33] Three respondents did not identify any method of use in their questionnaire responses.

addressed in the questionnaire. If this questionnaire is representative, it does indicate that merely teaching and training about EVM is not sufficient to convince managers to value the tool.

While the questionnaire results could be broken down and analyzed in any number of additional ways, the authors believe these propositions are the most relevant to answer the question of whether EVM is used by F-22 personnel to manage the program. The following final chapter will address the authors' findings regarding this and other questions posed in this paper.

## E. SUMMARY

This concludes Chapter IV, *F-22 EVMS Environment*. The next chapter, *Conclusion*, presents a condensed synopsis of this research project's outcome, includes a brief discussion on limitations with respect to the research project, and makes final recommendations to the EVMS where necessary.

# V. CONCLUSION

## A. SUMMARY OF FINDINGS

The intent of this study was to academically appraise the F-22 program's use of EVM in managing avionics software development within the Spiral 2 REDI contract effort, Delivery Orders 0002 and 0019. Achieving this goal involved performing and reporting the results of 1.) a detailed, data-supported evaluation of how the program meets each of the 32 ANSI/EIA EVMS criteria; 2.) interviews with subject-matter experts; 3.) a statistical questionnaire conducted with government and contractor personnel involved in F-22 software development. In order to facilitate the assessment, there were three questions asked by the authors. The following are the findings and recommendations associated with each question:

### 1. How Closely Did Implementation of EVM Follow ANSI/EIA Criteria?

#### *a. Findings*

Answering "How closely did the F-22 Spiral 2 implementation of EVM follow the criteria outlined in ANSI/EIA-748-A-1998 Earned Value Management System?" relied mainly on a careful assessment of how EVM implementation for Spiral 2 supported the 32 ANSI criteria. Based on the review of the objective of each criterion, the F-22 self-described implementation of the criteria, and interviews, data, and direct observation an assessment was made for each of the 32 criterion. These assessments were solely those of the authors and do not represent an official government position on the F-22 implementation of their EVMS. A summary of the 32 criteria assessments are as follows: seven excellent criteria, 15 satisfactory criteria, five marginal criteria, and one insufficient criterion, and four inconclusive criteria. With 22 (69 percent) of the 32 criteria assessed as satisfactory of better, the F-22 implementation of EVM was fairly strong; however, improvement of the F-22—and follow-on programs'—use of EVM during software development strongly depends on a discussion of the marginal and insufficient criteria.

Although there were five criteria deemed marginal, three of the five criteria were in one of the five criteria groups. Three of the ten Planning, Scheduling and Budgeting criteria were marginal. Another criterion could not be assessed sufficiently for a rating due to lack of supporting data. This trend was consistent with discussions and direct observations regarding the environment of F-22 development. As discussed in Chapter IV, F-22 EVMS Environment, the use of undefinitized contracts and requirements instability made it extremely difficult to adequately plan, schedule and budget for Spiral 2 efforts.

Criterion #26, Implement managerial actions, was the only criterion to be assessed as insufficient. This was largely based on the apparent absence of managerial actions taken on DO 0002 even as it had excessive variances and progressed toward a significant cost underrun. While it seems counter-intuitive to criticize a cost underrun, if corrective measures had been taken earlier, the program may have been able to capitalize on these additional funds before DO 0002 work was completed. The potential reasons for the failure of the program to take managerial actions are discussed in the following section. Suffice it to say, it does little good to collect EVM data if the program chooses not to use it.

#### *b. Recommendations*

If EVM is to be successfully used by F-22 personnel to manage avionics development, research data suggests that program managers dedicate themselves towards moving away from the use of undefinitized contracts. While this is easier stated than it is accomplished, based on the goals and intent of many of the ANSI/EIA EVMS Criteria, EVMS will not be fully useful as a management tool to F-22 as long as it is used in concert with undefinitized contracts.

A process for ensuring more disciplined control of requirements should be sought after. Research showed that stable requirements are critical for reliable, maturing EVM products. Group 2 of the ANSI/EIA EVMS Criteria focus on Planning, Scheduling and Budgeting. It is difficult if not impossible to meet the intent of the criteria outlined under this area if requirements are not well-defined.

### 2. To What Degree Did Implementation of EVM Fulfill Its Management Control Role?

#### *a. Findings*

In Chapter II, Literature Review, there were historical indicators that the F-22 program either chose to ignore or did not have confidence in the message that EVM was providing during EMD. After collecting and analyzing Spiral 2 CPR data along with assessing responses to the EVM Questionnaire, the authors' conclusion was there are still problems within the F-22 program in this area. One driver for the lack of use of EVM as a management tool is lack of confidence in EVM. It could not be determined whether this was due to unique F-22 problems (e.g., rolling and/or immature PMB) or to a more general lack of perceived EVM value. Both questionnaire results and interviews did indicate less use of EVM on the part of the government compared to the contractor. This could have been due to the significant time delay between when contractor managers first see EVM data and when government managers finally see it.

When considering managerial tools for use, the timeliness of the data is critical. However, the bottleneck in this instance appeared to be LM Aero business practices, not the EVMS. Streamlining these business practices should be considered paramount when attempting to shorten the timeline between EVM data collection and reporting.

The analysis of Spiral 2 EVM reports did indicate some errors in accounting/reporting; however, none of these attained a magnitude sufficient enough to bring into question the usefulness of the EVM reports. While there should be questions asked regarding these errors to ensure accurate, trustworthy reporting, the authors did not believe these errors were systemic in nature. The Spiral 2 data, like the EMD data, had a story to tell. As discussed above, there was a lack of action in response to this data. This did not appear to be a result of some malfunction of the F-22 EVMS, but rather inaction on the part of program managers.

### *b. Recommendations*

If EVM is to fulfill its role as a managerial tool in the F-22 program, research concludes that steps should be taken to ensure government access to EVM data in a timelier manner. Options should be explored and steps taken to leverage current customer-oriented industry practices that employ business procedures to shorten response timelines (including customer reports). Data suggests that investment into such process optimization will allow a more complete utilization of any EVMS.

## 3. To What Extent Did F-22 Management Use EVM to Manage Avionics Development?

### *a. Findings*

The EVM Questionnaire aimed to assess the perceived usefulness of EVM within a software development context and to assess F-22 managers' perceived value of EVM with respect to their management duties. Interviews supplemented the data from the questionnaire, figuratively filling in the questionnaire's information gaps uncovered throughout the course of the research project. Combining these assessment tools with those used for the other areas of research provided a full picture of how F-22 avionics managers use EVM. Questionnaire results indicated there is a somewhat low perceived value for EVM. Additionally, there were indications that EVM is used more as a tool for receiving and reporting cost and schedule status versus using it as a tool for proactively managing the development effort. Based on interviews conducted with several F-22 avionics managers, this becomes truer as software development efforts progress from design towards coding and into integration and testing. The more defined the tasks, the more confidence existed in EVM reports. As programs such as Spiral 2 moved toward less defined tasks, the less value was placed on EVM and the less it was used as a management tool.

#### *b. Recommendations*

Results of the data analysis and questionnaire analysis indicate a clear trend of F-22 managers either ignoring EVMS data or not using it enough for it to be considered an active management tool. The authors submit this is largely due to the perceived value of F-22 EVMS products. Regardless of whether it's driven by the managers' knowledge of F-22 EVMS flaws (as pointed out in this paper) or by a more generic lack of appreciation for EVMS as a management tool, if the F-22 software development programs are going to take advantage of the benefits of EVMS, the program must first establish confidence in it. Some of this confidence can be gained by implementing earlier recommendations that would make available more reliable, stable and timely data to government and contractor managers. Additional confidence could be gained by providing focused training for software development managers on the strengths and weaknesses of EVMS with respect to software development. This would enable managers to become more knowledgeable regarding how program decisions (such as proceeding with UCAs) affect the value and usefulness of EVM.

EVMS is particularly useful in the early stages of software development; however, research indicates it becomes less reliable and useful as the software development program progress through integration and test. Although a suggestion of a another software management tool is beyond the scope of this research project, the F-22 program should leverage off of knowledgeable resources such as the Carnegie Mellon Software Engineering Institute and the USAF Software Technology Support Center to explore the use of other management tools to either augment or replace EVM during the latter stages of software development.

### 4. Summary

The cumulative effect of assessing the criteria, evaluating the Spiral 2 EVM data and assessing questionnaire responses along with interview statements indicated that in the case of Spiral 2, there is a limited use of EVM by F-22 personnel in managing avionics development efforts. It is necessary for the program to evaluate the reasons behind this conclusion, whether it was lack of perceived value, lack of understanding of its function, or lack of confidence in the data. Regardless of the reason, data suggests that the F-22 program management should either take steps to address better use of EVM or identify other management tools in its stead. Either of these actions will help assure the program avoids repeating performance challenges endured during EMD.

## B. LIMITATIONS

Within the context of this project, every effort had been made towards a full assessment of the F-22 avionics program's EVM implementation, replete with all essential information. Unfortunately, reality dictated something less than full collection of required data. Regardless of completeness, the very information collected during the course of this academic pursuit may represent an outcome approximating, rather than equal to, the reality of the situation. As such, several limiting factors with regard to this particular study must, in the name of full academic disclosure, come to light.

To begin with, the nature of cutting-edge weapons systems like the F-22 dictated that certain information remained, in some cases, privileged. Thus, during the course of this study's investigative phase some information collected was accompanied with instructions to disseminate in a general manner, as opposed to reporting details that may or may not have altered this project's outcome or its readers' opinions. This requirement also pertained to first-hand knowledge that the authors may or may not have added to this paper's findings.

Secondly, and in a much-related matter, the nature of government and defense contractor relations necessitated a certain amount of caution during the course of interactions between representatives of the two parties. Unfortunately, though both parties make sincere efforts to maintain a mutually beneficial environment of information sharing, in the past both parties have failed to ensure that the sharing of sensitive information (e.g., Government Budgets, "Insider" schedule and cost reports) does not harm the party sharing that potentially inflammatory data. As a result, this project's investigative efforts fell short of acquiring some data initially requested from the contractor.

Finally, the analysis phase of this project has uncovered issues regarding the EVM Questionnaire. The first issue dealt with the small and specific population size that the questionnaire analysis depends upon. This introduced biases rooted in program culture and program-specific training, even within the context of the F-22 SPO / LM Aeronautics: F-22. Thus, should problem areas with respect to EVM implementation become visible, an analysis of questionnaire data may or may not uncover systemic causalities that "perfect" information might identify.

The second questionnaire issue involved the discrete values assigned to the EVM Questionnaire queries. For example, Question #3's possible answer began with "Never" and proceeds to "Once a Month". Post-submission analysis indicated that a substantial number of personnel, especially those not identifying "Financial Management" as their "current role", actually would answer somewhere in-between these given choices (i.e., more than "Never" but less than "Once a Month"). Thus, though careful thought went into the questionnaire design and implementation, the discrete choices given to respondents appeared to have affected the questionnaire analysis.

Limitations aside, the information gathered and interpreted provided sound data collection, results, and recommendations given realistic constraints that would affect any similar undertaking. An honest appraisal of research limitations should not preclude the fact that perfect information almost never avails itself to those who seek it. That said, the remainder of this chapter reviews the highlights of this study and presents recommendations for consideration.

## C. AREAS FOR FUTURE STUDIES

Although the authors sought to extensively assess the use of EVM in the F-22 program, several areas for further study were identified on this topic. The first was in the area of applicability of EVM to the latter stages of software development. As software development progresses from well-defined tasks such as development of design documents, writing code and developing test plans to less defined tasks such as recode and retest, EVM becomes less useful as a management tool. Research in the area of potential approaches for measuring value in this less-defined regime would be valuable.

Spiral 2 has not yet completed its DO 0019 effort which is largely comprised of these "less-defined" tasks. A study of how EVM implementation was employed at the conclusion of this delivery order would be useful in identifying potential alternatives or variations to current EVM implementation.

F-22 is plagued with reliance on undefinitized contractual actions. Considering many of the challenges facing F-22 are not unique, it is reasonable to assume excessive use of UCAs is also not unique. Research into the trends and impacts of this type of contractual approach might provide further information to managers and contract officers. UCAs are not wrong; however, their use does come with consequences. Research that quantified these consequences would be useful.

Another challenge identified for the F-22 program was the timeliness of EVM reports to government managers. This is also not an issue unique to the F-22 program. As the authors discussed, there are valid reasons behind the delay in providing trusted EVM data to the government; however, there are potential solutions to these challenges.[34] Research into the major drivers for this reporting delay, potential solutions, and costs associated with these solutions could provide DoD some viable options to solve this issue and make EVM as valuable to the government as it is to the contractor.

[34] See Recommendations for Research Question #2.

# APPENDIX A – SPIRAL 2 DO 0002 COST AND EVM DATA

SPIRAL 2 PHASE B: EV DATA

Work Prior to Initial Reporting Period (Pre-April 2004)

(000s)

| | CURRENT PERIOD | | | | | CUMULATIVE TO DATE | | | | | AT COMPLETION | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BCWS | BCWP | ACWP | SV | CV | BCWS | BCWP | ACWP | SV | CV | BAC | LRE | VAC | $ETC_{LRE}$ |
| **F-22 Modernization REDI DO0002** | **327** | **186** | **42** | **(141)** | **144** | **327** | **186** | **42** | **(141)** | **144** | **36,012** | **36,012** | - | **35,685** |
| **Air Vehicle** | **13** | **10** | **2** | **(3)** | **8** | **13** | **10** | **2** | **(3)** | **8** | **746** | **746** | - | **733** |
| Air Vehicle Seit | 8 | 7 | - | (1) | 7 | 8 | 7 | - | (1) | 7 | 683 | 683 | - | 675 |
| Air Vehicle Systems | 5 | 3 | 2 | (2) | 1 | 5 | 3 | 2 | (2) | 1 | 63 | 63 | - | 58 |
| **Build Team** | - | - | - | - | - | - | - | - | - | - | **162** | **162** | - | **162** |
| **Mission Sys & SW** | **257** | **121** | **29** | **(136)** | **93** | **257** | **121** | **29** | **(136)** | **93** | **22,130** | **22,124** | **6** | **21,867** |
| Avionics Seit | 140 | 8 | 13 | (132) | (5) | 140 | 8 | 13 | (132) | (5) | 5,091 | 5,087 | 4 | 4,947 |
| Core Processing | - | - | 5 | - | (5) | - | - | 5 | - | (5) | 5,197 | 5,197 | - | 5,197 |
| CNI | 30 | 26 | - | (4) | 26 | 30 | 26 | - | (4) | 26 | 310 | 310 | - | 280 |
| Display Prod | - | - | - | - | - | - | - | - | - | - | 30 | 30 | - | 30 |
| Electronic Warfare | 1 | 1 | - | - | 1 | 1 | 1 | - | - | 1 | 3,173 | 3,173 | - | 3,172 |
| Mission Avionics Software | 39 | 39 | 11 | - | 28 | 39 | 39 | 11 | - | 28 | 2,358 | 2,358 | - | 2,319 |
| Radar | - | - | - | - | - | - | - | - | - | - | 4,412 | 4,410 | 2 | 4,410 |
| Stores Mgmt Sys | 47 | 47 | - | - | 47 | 47 | 47 | - | - | 47 | 1,558 | 1,558 | - | 1,511 |
| **Sustainment & Mods** | - | - | - | - | - | - | - | - | - | - | **4,577** | **4,577** | - | **4,577** |
| Mods & Heavy Maint | - | - | - | - | - | - | - | - | - | - | 11 | 11 | - | 11 |
| Support Equipment | - | - | - | - | - | - | - | - | - | - | 163 | 163 | - | 163 |
| Support Services | - | - | - | - | - | - | - | - | - | - | 42 | 42 | - | 42 |
| Support Data & Int Main IS | - | - | - | - | - | - | - | - | - | - | 190 | 190 | - | 190 |
| Training | - | - | - | - | - | - | - | - | - | - | 4,171 | 4,171 | - | 4,171 |
| **Weapon System I&T** | **45** | **43** | **10** | **(2)** | **33** | **45** | **43** | **10** | **(2)** | **33** | **984** | **984** | - | **939** |
| Flight Test | 2 | 2 | - | - | 2 | 2 | 2 | - | - | 2 | 125 | 125 | - | 123 |
| FTS Instr | 13 | 13 | - | - | 13 | 13 | 13 | - | - | 13 | 137 | 137 | - | 124 |
| Test Plan & Supt | 30 | 28 | 10 | (2) | 18 | 30 | 28 | 10 | (2) | 18 | 692 | 692 | - | 662 |
| System Integ | - | - | - | - | - | - | - | - | - | - | 30 | 30 | - | 30 |
| **Program Operations** | **12** | **12** | - | - | **12** | **12** | **12** | - | - | **12** | **6,168** | **6,174** | **(6)** | **6,162** |
| **Modernization** | - | - | **1** | - | **(1)** | - | - | **1** | - | **(1)** | **1,245** | **1,245** | - | **1,245** |
| | | | | | | | | | | **UB** | **5,032** | **5,032** | - | |
| | | | | | | | | | | **MR** | **4,999** | **4,999** | - | |
| | | | | | | | | | | **TOTAL** | **46,043** | **46,043** | - | |

Notes

At this point, the project was behind schedule by 141K and also (appropriately) undercost by 144K.

Data lacks verification past whole-number values; thus, rounding errors have occurred.

| | |
|---|---|
| **Contract Budget Base** | **46,043** |
| **Delta** | **-** |

SPIRAL 2 PHASE B: EV DATA

April 2004

(000s)

| | CURRENT PERIOD | | | | | CUMULATIVE TO DATE | | | | | AT COMPLETION | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BCWS | BCWP | ACWP | SV | CV | BCWS | BCWP | ACWP | SV | CV | BAC | LRE | VAC | $ETC_{LRE}$ |
| **F-22 Modernization REDI DO0002** | **1,506** | **1,475** | **814** | **(31)** | **660** | **1,833** | **1,661** | **857** | **(172)** | **804** | **36,012** | **36,012** | - | **35,155** |
| **Air Vehicle** | **21** | **19** | **20** | **(2)** | **(2)** | **34** | **29** | **22** | **(5)** | **6** | **746** | **746** | - | **724** |
| Air Vehicle Seit | 15 | 12 | 9 | (4) | 2 | 23 | 19 | 9 | (5) | 9 | 683 | 683 | - | 674 |
| Air Vehicle Systems | 5 | 7 | 11 | 2 | (4) | 10 | 10 | 13 | (0) | (3) | 63 | 63 | - | 50 |
| **Build Team** | - | - | - | - | - | - | - | - | - | - | **162** | **162** | - | **162** |
| **Mission Sys & SW** | **1,168** | **1,145** | **582** | **(23)** | **563** | **1,425** | **1,266** | **611** | **(159)** | **656** | **22,130** | **22,124** | **6** | **21,513** |
| Avionics Seit | 573 | 525 | 165 | (48) | 360 | 713 | 533 | 178 | (180) | 356 | 5,091 | 5,087 | 4 | 4,910 |
| Core Processing | 375 | 317 | 195 | (58) | 122 | 375 | 317 | 200 | (58) | 117 | 5,197 | 5,197 | - | 4,997 |
| CNI | 31 | 27 | 15 | (4) | 12 | 61 | 53 | 15 | (8) | 38 | 310 | 310 | - | 295 |
| Display Prod | 2 | 2 | 2 | - | - | 2 | 2 | 2 | - | - | 30 | 30 | - | 28 |
| Electronic Warfare | 2 | 2 | - | - | 2 | 3 | 3 | - | - | 3 | 3,173 | 3,173 | - | 3,173 |
| Mission Avionics Software | 39 | 126 | 153 | 87 | (27) | 78 | 165 | 164 | 87 | 1 | 2,358 | 2,358 | - | 2,194 |
| Radar | 81 | 81 | 14 | - | 67 | 81 | 81 | 14 | - | 67 | 4,412 | 4,410 | 2 | 4,396 |
| Stores Mgmt Sys | 65 | 65 | 38 | - | 27 | 112 | 112 | 38 | - | 74 | 1,558 | 1,558 | - | 1,520 |
| **Sustainment & Mods** | **89** | **89** | **50** | - | **39** | **89** | **89** | **50** | - | **39** | **4,577** | **4,577** | - | **4,527** |
| Mods & Heavy Maint | 1 | 1 | - | - | 1 | 1 | 1 | - | - | 1 | 11 | 11 | - | 11 |
| Support Equipment | 18 | 18 | 2 | - | 16 | 18 | 18 | 2 | - | 16 | 163 | 163 | - | 161 |
| Support Services | 4 | 4 | 2 | - | 2 | 4 | 4 | 2 | - | 2 | 42 | 42 | - | 40 |
| Support Data & Int Main IS | 21 | 21 | - | - | 21 | 21 | 21 | - | - | 21 | 190 | 190 | - | 190 |
| Training | 44 | 44 | 46 | - | (2) | 44 | 44 | 46 | - | (2) | 4,171 | 4,171 | - | 4,125 |
| **Weapon System I&T** | **58** | **52** | **74** | **(6)** | **(22)** | **103** | **95** | **84** | **(8)** | **11** | **984** | **984** | - | **900** |
| Flight Test | 2 | 2 | - | - | 2 | 4 | 4 | - | - | 4 | 125 | 125 | - | 125 |
| FTS Instr | 13 | 13 | 1 | - | 12 | 26 | 26 | 1 | - | 25 | 137 | 137 | - | 136 |
| Test Plan & Supt | 43 | 37 | 73 | (6) | (36) | 73 | 65 | 83 | (8) | (18) | 692 | 692 | - | 609 |
| System Integ | - | - | - | - | - | - | - | - | - | - | 30 | 30 | - | 30 |
| **Program Operations** | **131** | **131** | **74** | - | **57** | **143** | **143** | **74** | - | **69** | **6,168** | **6,174** | **(6)** | **6,100** |
| **Modernization** | **39** | **39** | **14** | - | **25** | **39** | **39** | **15** | - | **24** | **1,245** | **1,245** | - | **1,230** |
| | | | | | | | | | | **UB** | **5,032** | **5,032** | - | |
| | | | | | | | | | | **MR** | **4,999** | **4,999** | - | |
| | | | | | | | | | | **TOTAL** | **46,043** | **46,043** | - | |
| | | | | | | | | | | **Contract Budget Base** | | **46,043** | | |
| | | | | | | | | | | | **Delta** | - | | |

Notes

At this point, the project was behind schedule by 31K and undercost by 660K; behind schedule and undercost together make sense, but not for the amounts calculated.

Data lacks verification past whole-number values; thus, rounding errors have occurred.

SPIRAL 2 PHASE B: EV DATA

May 2004

(000s)

| | CURRENT PERIOD | | | | | CUMULATIVE TO DATE | | | | | AT COMPLETION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BCWS | BCWP | ACWP | SV | CV | BCWS | BCWP | ACWP | SV | CV | BAC | $\Delta_{prev\ mth}$ | LRE | $\Delta_{prev\ mth}$ | VAC | $ETC_{LRE}$ |
| **F-22 Modernization REDI DO0002** | **2,602** | **2,905** | **1,513** | **303** | **1,392** | **4,435** | **4,566** | **2,370** | **131** | **2,196** | **36,263** | **251** | **36,264** | **252** | **(1)** | **33,894** |
| **Air Vehicle** | **55** | **60** | **52** | **5** | **8** | **89** | **89** | **74** | **-** | **14** | **703** | **(43)** | **703** | **(43)** | **-** | **629** |
| Air Vehicle Seit | 48 | 46 | 45 | (2) | 1 | 71 | 65 | 54 | (7) | 10 | 643 | (40) | 643 | (40) | - | 589 |
| Air Vehicle Systems | 7 | 14 | 7 | 7 | 7 | 17 | 24 | 20 | 7 | 4 | 60 | (3) | 60 | (3) | - | 40 |
| **Build Team** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **-** | **150** | **(12)** | **150** | **(12)** | **-** | **150** |
| **Mission Sys & SW** | **1,427** | **1,714** | **1,146** | **287** | **568** | **2,852** | **2,980** | **1,757** | **128** | **1,224** | **22,308** | **178** | **22,297** | **173** | **11** | **20,541** |
| Avionics Seit | 444 | 512 | 360 | 68 | 152 | 1,157 | 1,045 | 538 | (112) | 508 | 6,945 | 1,854 | 6,940 | 1,853 | 5 | 6,403 |
| Core Processing | 432 | 462 | 338 | 30 | 124 | 807 | 779 | 538 | (28) | 241 | 5,197 | - | 5,194 | (3) | 3 | 4,656 |
| CNI | 38 | 33 | 35 | (5) | (2) | 99 | 86 | 50 | (13) | 36 | 523 | 213 | 523 | 213 | - | 473 |
| Display Prod | 4 | 5 | 3 | 1 | 2 | 6 | 7 | 5 | 1 | 2 | 273 | 243 | 273 | 243 | - | 268 |
| Electronic Warfare | 2 | 2 | - | - | 2 | 5 | 5 | - | - | 5 | 725 | (2,448) | 725 | (2,448) | - | 725 |
| Mission Avionics Software | 282 | 393 | 266 | 111 | 127 | 360 | 558 | 430 | 198 | 128 | 2,770 | 412 | 2,770 | 412 | - | 2,340 |
| Radar | 119 | 119 | 31 | - | 88 | 200 | 200 | 45 | - | 155 | 4,412 | - | 4,409 | (1) | 3 | 4,364 |
| Stores Mgmt Sys | 106 | 188 | 113 | 82 | 75 | 218 | 300 | 151 | 82 | 149 | 1,463 | (95) | 1,463 | (95) | - | 1,312 |
| **Sustainment & Mods** | **194** | **194** | **70** | **-** | **124** | **283** | **283** | **120** | **-** | **163** | **4,556** | **(21)** | **4,564** | **(13)** | **(8)** | **4,444** |
| Mods & Heavy Maint | 2 | 2 | - | - | 2 | 3 | 3 | - | - | 3 | 11 | - | 11 | - | - | 11 |
| Support Equipment | 18 | 18 | 8 | - | 10 | 36 | 36 | 10 | - | 26 | 154 | (9) | 154 | (9) | - | 144 |
| Support Services | 5 | 5 | 2 | - | 3 | 9 | 9 | 4 | - | 5 | 40 | (2) | 40 | (2) | - | 36 |
| Support Data & Int Main IS | 22 | 22 | 3 | - | 19 | 43 | 43 | 3 | - | 40 | 180 | (10) | 180 | (10) | - | 177 |
| Training | 147 | 147 | 57 | - | 90 | 191 | 191 | 103 | - | 88 | 4,171 | - | 4,179 | 8 | (8) | 4,076 |
| **Weapon System I&T** | **77** | **88** | **92** | **11** | **(4)** | **180** | **183** | **176** | **3** | **7** | **937** | **(47)** | **937** | **(47)** | **-** | **761** |
| Flight Test | 20 | 20 | - | - | 20 | 24 | 24 | - | - | 24 | 124 | (1) | 124 | (1) | - | 124 |
| FTS Instr | 16 | 16 | 16 | - | - | 42 | 42 | 17 | - | 25 | 130 | (7) | 130 | (7) | - | 113 |
| Test Plan & Supt | 37 | 48 | 76 | 11 | (28) | 110 | 113 | 159 | 3 | (46) | 653 | (39) | 653 | (39) | - | 494 |
| System Integ | 4 | 4 | - | - | 4 | 4 | 4 | - | - | 4 | 30 | - | 30 | - | - | 30 |
| **Program Operations** | **331** | **331** | **130** | **-** | **201** | **474** | **474** | **204** | **-** | **270** | **6,412** | **244** | **6,416** | **242** | **(4)** | **6,212** |
| **Modernization** | **518** | **518** | **23** | **-** | **495** | **557** | **557** | **38** | **-** | **519** | **1,197** | **(48)** | **1,197** | **(48)** | **-** | **1,159** |
| | | | | | | | | | | **UB** | **4,781** | **(251)** | **4,781** | **(251)** | **-** | |
| | | | | | | | | | | **MR** | **4,999** | - | **4,999** | - | **-** | |
| | | | | | | | | | | **TOTAL** | **46,043** | **0** | **46,044** | **1** | **(1)** | |

**Contract Budget Base** 46,043

**Delta** -

Notes

For this period, the project was ahead of schedule by 303K and undercost by $1.4M, further hinting at a disconnect between the PMB and actual work.

The BAC and LRE rose over 250K from last period, mostly due to increases in Mission Sys & SW and Program Operations.

Data lacks verification past whole-number values; thus, rounding errors have occurred.

SPIRAL 2 PHASE B: EV DATA

Jun 2004

(000s)

| | CURRENT PERIOD | | | | | CUMULATIVE TO DATE | | | | | AT COMPLETION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BCWS | BCWP | ACWP | SV | CV | BCWS | BCWP | ACWP | SV | CV | BAC | Δ | LRE | Δ | VAC | $ETC_{LRE}$ |
| **F-22 Modernization REDI DO0002** | **2,428** | **2,128** | **1,660** | **(300)** | **468** | **6,863** | **6,694** | **4,030** | **(169)** | **2,664** | **37,054** | 791 | **37,054** | 790 | **(0)** | **33,025** |
| **Air Vehicle** | **96** | **54** | **61** | **(42)** | **(7)** | **185** | **143** | **135** | **(42)** | **7** | **699** | (4) | **699** | (4) | - | **564** |
| Air Vehicle Seit | 89 | 49 | 62 | (40) | (13) | 160 | 114 | 116 | (47) | (3) | 639 | (4) | 639 | (4) | - | 523 |
| Air Vehicle Systems | 7 | 5 | (1) | (2) | 6 | 24 | 29 | 19 | 5 | 10 | 60 | - | 60 | - | - | 41 |
| **Build Team** | - | - | **2** | - | **(2)** | - | - | **2** | - | **(2)** | **150** | - | **150** | - | - | **148** |
| **Mission Sys & SW** | **1,419** | **1,143** | **1,116** | **(276)** | **27** | **4,271** | **4,123** | **2,873** | **(148)** | **1,250** | **23,395** | 1,087 | **23,385** | 1,088 | **10** | **20,512** |
| Avionics Seit | 482 | 457 | 331 | (25) | 126 | 1,639 | 1,502 | 869 | (137) | 634 | 7,182 | 237 | 7,178 | 238 | 4 | 6,310 |
| Core Processing | 494 | 511 | 386 | 17 | 125 | 1,301 | 1,290 | 924 | (11) | 366 | 5,197 | - | 5,194 | - | 3 | 4,270 |
| CNI | 29 | 46 | 31 | 17 | 15 | 128 | 132 | 81 | 4 | 51 | 520 | (3) | 520 | (3) | - | 439 |
| Display Prod | 4 | 4 | 6 | - | (2) | 10 | 11 | 11 | 1 | - | 273 | - | 273 | - | - | 262 |
| Electronic Warfare | 1 | 1 | 0 | - | 1 | 6 | 6 | 0 | - | 6 | 724 | (1) | 724 | (1) | - | 724 |
| Mission Avionics Software | 247 | 119 | 211 | (128) | (92) | 607 | 677 | 641 | 70 | 36 | 2,750 | (20) | 2,750 | (20) | - | 2,109 |
| Radar | 56 | 56 | 26 | - | 30 | 256 | 256 | 71 | - | 185 | 4,412 | - | 4,409 | - | 3 | 4,338 |
| Stores Mgmt Sys | 106 | (51) | 125 | (157) | (176) | 324 | 249 | 276 | (75) | (27) | 2,337 | 874 | 2,337 | 874 | - | 2,061 |
| **Sustainment & Mods** | **410** | **410** | **153** | - | **257** | **693** | **693** | **273** | - | **420** | **4,553** | (3) | **4,561** | (3) | **(8)** | **4,288** |
| Mods & Heavy Maint | 1 | 1 | - | - | 1 | 4 | 4 | - | - | 4 | 11 | - | 11 | - | - | 11 |
| Support Equipment | 17 | 17 | 24 | - | (7) | 53 | 53 | 34 | - | 19 | 153 | (1) | 153 | (1) | - | 119 |
| Support Services | 4 | 4 | 12 | - | (8) | 13 | 13 | 16 | - | (3) | 40 | - | 40 | - | - | 24 |
| Support Data & Int Main IS | 20 | 20 | 57 | - | (37) | 63 | 63 | 60 | - | 3 | 178 | (2) | 178 | (2) | - | 118 |
| Training | 368 | 368 | 60 | - | 308 | 559 | 559 | 163 | - | 396 | 4,171 | - | 4,179 | - | (8) | 4,016 |
| **Weapon System I&T** | **64** | **82** | **108** | **18** | **(26)** | **244** | **265** | **285** | **21** | **(20)** | **934** | (3) | **934** | (3) | - | **649** |
| Flight Test | 6 | 6 | 0 | - | 6 | 30 | 30 | 0 | - | 30 | 124 | - | 124 | - | - | 124 |
| FTS Instr | 12 | 12 | 18 | - | (6) | 54 | 54 | 35 | - | 19 | 129 | (1) | 129 | (1) | - | 94 |
| Test Plan & Supt | 42 | 60 | 90 | 18 | (30) | 152 | 173 | 249 | 21 | (76) | 651 | (2) | 651 | (2) | - | 402 |
| System Integ | 4 | 4 | - | - | 4 | 8 | 8 | - | - | 8 | 30 | - | 30 | - | - | 30 |
| **Program Operations** | **363** | **363** | **206** | - | **157** | **837** | **837** | **410** | - | **427** | **6,161** | (251) | **6,164** | (252) | **(3)** | **5,754** |
| **Modernization** | **76** | **76** | **13** | - | **63** | **633** | **633** | **51** | - | **582** | **1,161** | (36) | **1,161** | (36) | **0** | **1,110** |

| | BAC | Δ | LRE | Δ | VAC |
|---|---|---|---|---|---|
| **UB** | **3,990** | (791) | **3,990** | (791) | - |
| **MR** | **4,999** | - | **4,999** | - | - |
| **TOTAL** | **46,043** | (0) | **46,043** | (1) | **(0)** |

**Contract Budget Base** 46,043

**Delta** -

Notes

For this period, the project was behind schedule by $300K and also undercost by $468K (cum underrun = $2.7M).

The BAC and LRE rose over $790K from last period, mostly due to increases in Mission Sys & SW.

Data lacks verification past whole-number values; thus, rounding errors have occurred.

SPIRAL 2 PHASE B: EV DATA

July 2004

(000s)

| | CURRENT PERIOD | | | | | CUMULATIVE TO DATE | | | | | AT COMPLETION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BCWS | BCWP | ACWP | SV | CV | BCWS | BCWP | ACWP | SV | CV | BAC | $\Delta_{prev\ mth}$ | LRE | $\Delta_{prev\ mth}$ | VAC | $ETC_{LRE}$ |
| **F-22 Modernization REDI DO0002** | **2,433** | **2,517** | **1,600** | **84** | **917** | **9,296** | **9,211** | **5,629** | **(85)** | **3,582** | **37,054** | - | **37,054** | - | **(0)** | **31,425** |
| **Air Vehicle** | **97** | **42** | **36** | **(55)** | **6** | **282** | **185** | **171** | **(97)** | **13** | **699** | - | **699** | - | **-** | **528** |
| Air Vehicle Seit | 92 | 39 | 29 | (53) | 10 | 252 | 153 | 145 | (100) | 7 | 639 | - | 639 | - | - | 494 |
| Air Vehicle Systems | 5 | 3 | 7 | (2) | (4) | 29 | 32 | 26 | 3 | 6 | 60 | - | 60 | - | - | 34 |
| **Build Team** | **25** | **25** | **9** | **-** | **16** | **25** | **25** | **11** | **-** | **14** | **150** | - | **150** | - | **-** | **139** |
| **Mission Sys & SW** | **1,739** | **1,886** | **1,107** | **147** | **779** | **6,010** | **6,009** | **3,980** | **(1)** | **2,030** | **23,395** | - | **23,100** | **(285)** | **295** | **19,121** |
| Avionics Seit | 531 | 503 | 440 | (28) | 63 | 2,170 | 2,005 | 1,309 | (165) | 697 | 7,182 | - | 7,081 | (97) | 101 | 5,773 |
| Core Processing | 692 | 678 | 283 | (14) | 395 | 1,993 | 1,968 | 1,207 | (25) | 761 | 5,197 | - | 5,010 | (184) | 187 | 3,803 |
| CNI | 25 | 24 | 15 | (1) | 9 | 153 | 156 | 96 | 3 | 60 | 520 | - | 520 | - | - | 424 |
| Display Prod | 2 | 5 | 6 | 3 | (1) | 12 | 16 | 17 | 4 | (1) | 273 | - | 273 | - | - | 256 |
| Electronic Warfare | 1 | 1 | (0) | - | 1 | 7 | 7 | - | - | 7 | 724 | - | 724 | - | - | 724 |
| Mission Avionics Software | 245 | 246 | 220 | 1 | 26 | 852 | 923 | 861 | 71 | 62 | 2,750 | - | 2,750 | - | - | 1,889 |
| Radar | 67 | 67 | 10 | - | 57 | 323 | 323 | 81 | - | 242 | 4,412 | - | 4,405 | (4) | 7 | 4,324 |
| Stores Mgmt Sys | 176 | 362 | 133 | 186 | 229 | 500 | 611 | 409 | 111 | 202 | 2,337 | - | 2,337 | - | - | 1,928 |
| **Sustainment & Mods** | **(21)** | **(21)** | **143** | **-** | **(164)** | **672** | **672** | **416** | **-** | **256** | **4,553** | - | **4,510** | **(51)** | **43** | **4,094** |
| Mods & Heavy Maint | 1 | 1 | - | - | 1 | 5 | 5 | - | - | 5 | 11 | - | 11 | - | - | 11 |
| Support Equipment | 17 | 17 | 4 | - | 13 | 70 | 70 | 38 | - | 32 | 154 | 1 | 153 | - | 1 | 115 |
| Support Services | 4 | 4 | 6 | - | (2) | 17 | 17 | 22 | - | (5) | 39 | (1) | 39 | (1) | - | 17 |
| Support Data & Int Main IS | 20 | 20 | 68 | - | (48) | 83 | 83 | 128 | - | (45) | 178 | - | 178 | - | - | 50 |
| Training | (63) | (63) | 65 | - | (128) | 496 | 496 | 228 | - | 268 | 4,171 | - | 4,129 | (50) | 42 | 3,901 |
| **Weapon System I&T** | **80** | **72** | **62** | **(8)** | **10** | **324** | **337** | **347** | **13** | **(10)** | **934** | - | **930** | **(4)** | **4** | **583** |
| Flight Test | 3 | 3 | 6 | - | (3) | 33 | 33 | 6 | - | 27 | 124 | - | 121 | (3) | 3 | 115 |
| FTS Instr | 12 | 12 | 14 | - | (2) | 66 | 66 | 49 | - | 17 | 129 | - | 129 | - | - | 80 |
| Test Plan & Supt | 61 | 53 | 42 | (8) | 11 | 213 | 226 | 291 | 13 | (65) | 651 | - | 651 | - | - | 360 |
| System Integ | 4 | 4 | - | - | 4 | 12 | 12 | - | - | 12 | 30 | - | 29 | (1) | 1 | 29 |
| **Program Operations** | **437** | **437** | **231** | **-** | **206** | **1,274** | **1,274** | **641** | **-** | **633** | **6,161** | - | **6,504** | **340** | **(343)** | **5,863** |
| **Modernization** | **76** | **76** | **12** | **-** | **64** | **709** | **709** | **63** | **-** | **646** | **1,161** | - | **1,161** | - | **0** | **1,098** |
| **UB** | | | | | | | | | | | **3,990** | - | **3,990** | - | **-** | |
| **MR** | | | | | | | | | | | **4,999** | - | **4,999** | - | **-** | |
| **TOTAL** | | | | | | | | | | | **46,043** | - | **46,043** | - | **(0)** | |

Contract Budget Base 46,043

Delta 0

Notes

At this point, the project was behind schedule by 85K and undercost by $3.6M, further hinting at a disconnect between the PMB and actual work.

The BAC and LRE remained constant from last period, with funds shifting b/t Mission Sys & SW and Program Operations w/i LRE.

Data lacks verification past whole-number values; thus, rounding errors have occurred.

## SPIRAL 2 PHASE B: EV DATA

August 2004

(000s)

| | CURRENT PERIOD | | | | | CUMULATIVE TO DATE | | | | | AT COMPLETION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BCWS | BCWP | ACWP | SV | CV | BCWS | BCWP | ACWP | SV | CV | BAC | $\Delta_{prev\ mth}$ | LRE | $\Delta_{prev\ mth}$ | VAC | $ETC_{LRE}$ |
| **F-22 Modernization REDI DO0002** | **4,236** | **4,258** | **2,986** | **22** | **1,272** | **13,532** | **13,469** | **8,616** | **(63)** | **4,853** | **37,054** | - | **37,054** | - | **(0)** | **28,439** |
| **Air Vehicle** | **69** | **66** | **72** | **(3)** | **(6)** | **351** | **251** | **243** | **(100)** | **7** | **612** | (87) | **612** | (87) | - | **369** |
| Air Vehicle Seit | 63 | 57 | 62 | (6) | (5) | 315 | 210 | 207 | (106) | 2 | 552 | (87) | 552 | (87) | - | 345 |
| Air Vehicle Systems | 6 | 9 | 10 | 3 | (1) | 35 | 41 | 36 | 6 | 5 | 60 | - | 60 | - | - | 24 |
| **Build Team** | **25** | **25** | **4** | - | **21** | **50** | **50** | **15** | - | **35** | **150** | - | **150** | - | - | **135** |
| **Mission Sys & SW** | **3,296** | **3,291** | **2,331** | **(5)** | **960** | **9,306** | **9,300** | **6,311** | **(6)** | **2,989** | **23,395** | - | **23,100** | - | **295** | **16,789** |
| Avionics Seit | 910 | 883 | 430 | (27) | 453 | 3,080 | 2,888 | 1,739 | (192) | 1,150 | 7,182 | - | 7,081 | - | 101 | 5,343 |
| Core Processing | 581 | 531 | 295 | (50) | 236 | 2,574 | 2,499 | 1,502 | (75) | 997 | 5,197 | - | 5,010 | - | 187 | 3,508 |
| CNI | 33 | 31 | 14 | (2) | 17 | 186 | 187 | 110 | 1 | 77 | 520 | - | 520 | - | - | 410 |
| Display Prod | 6 | (1) | 6 | (7) | (7) | 18 | 15 | 23 | (3) | (8) | 273 | - | 273 | - | - | 250 |
| Electronic Warfare | 2 | 2 | 0 | - | 2 | 9 | 9 | 0 | - | 9 | 724 | - | 724 | - | - | 724 |
| Mission Avionics Software | 345 | 332 | 314 | (13) | 18 | 1,197 | 1,255 | 1,175 | 58 | 80 | 2,750 | - | 2,750 | - | - | 1,575 |
| Radar | 1,110 | 1,110 | 1,060 | - | 50 | 1,433 | 1,433 | 1,141 | - | 292 | 4,412 | - | 4,405 | - | 7 | 3,264 |
| Stores Mgmt Sys | 309 | 403 | 212 | 94 | 191 | 809 | 1,014 | 621 | 205 | 393 | 2,337 | - | 2,337 | - | - | 1,716 |
| **Sustainment & Mods** | **273** | **264** | **190** | **(9)** | **74** | **945** | **936** | **606** | **(9)** | **330** | **4,553** | - | **4,510** | - | **43** | **3,904** |
| Mods & Heavy Maint | 1 | 1 | - | - | 1 | 6 | 6 | - | - | 6 | 11 | - | 11 | - | - | 11 |
| Support Equipment | 20 | 17 | 4 | (3) | 13 | 90 | 87 | 42 | (3) | 45 | 154 | - | 153 | - | 1 | 111 |
| Support Services | 3 | 3 | 1 | - | 2 | 20 | 20 | 23 | - | (3) | 39 | - | 39 | - | - | 16 |
| Support Data & Int Main IS | 16 | 10 | 96 | (6) | (86) | 99 | 93 | 224 | (6) | (131) | 178 | - | 178 | - | - | (46) |
| Training | 233 | 233 | 89 | - | 144 | 729 | 729 | 317 | - | 412 | 4,171 | - | 4,129 | - | 42 | 3,812 |
| **Weapon System I&T** | **104** | **143** | **155** | **39** | **(12)** | **428** | **480** | **502** | **52** | **(22)** | **934** | - | **930** | - | **4** | **428** |
| Flight Test | 15 | 15 | 11 | - | 4 | 48 | 48 | 17 | - | 31 | 124 | - | 121 | - | 3 | 104 |
| FTS Instr | 15 | 15 | 51 | - | (36) | 81 | 81 | 100 | - | (19) | 129 | - | 129 | - | - | 29 |
| Test Plan & Supt | 70 | 109 | 93 | 39 | 16 | 283 | 335 | 384 | 52 | (49) | 651 | - | 651 | - | - | 267 |
| System Integ | 4 | 4 | - | - | 4 | 16 | 16 | - | - | 16 | 30 | - | 29 | - | 1 | 29 |
| **Program Operations** | **358** | **358** | **202** | - | **156** | **1,632** | **1,632** | **843** | - | **789** | **6,161** | - | **6,504** | - | **(343)** | **5,661** |
| **Modernization** | **111** | **111** | **32** | - | **79** | **820** | **820** | **95** | - | **725** | **1,248** | 87 | **1,248** | 87 | **0** | **1,153** |
| | | | | | | | | | | **UB** | **3,990** | - | **3,990** | - | - | |
| | | | | | | | | | | **MR** | **4,999** | - | **4,999** | - | - | |
| | | | | | | | | | | **TOTAL** | **46,043** | - | **46,043** | - | **(0)** | |

**Contract Budget Base** 46,043

**Delta** 0

Notes

At this point, the project was behind schedule by $63K and undercost by $4.9M, continuing a trend of growing underrun suggesting errors wrt the current PMB.

The BAC and LRE remained constant from last period, with funds shifting b/t Air Vehicle and Modernization.

Data lacks verification past whole-number values; thus, rounding errors have occurred.

## SPIRAL 2 PHASE B: EV DATA

September 2004

(000s)

| | CURRENT PERIOD | | | | | CUMULATIVE TO DATE | | | | | AT COMPLETION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BCWS | BCWP | ACWP | SV | CV | BCWS | BCWP | ACWP | SV | CV | BAC | $\Delta_{prev\ mth}$ | LRE | $\Delta_{prev\ mth}$ | VAC | $ETC_{LRE}$ |
| **F-22 Modernization REDI DO0002** | **4,431** | **4,092** | **2,648** | **(339)** | **1,444** | **17,963** | **17,561** | **11,264** | **(402)** | **6,297** | **37,054** | - | **37,055** | 1 | **(1)** | **25,791** |
| **Air Vehicle** | **53** | **43** | **40** | **(10)** | **3** | **404** | **294** | **283** | **(110)** | **10** | **612** | - | **612** | - | **-** | **329** |
| Air Vehicle Seit | 48 | 36 | 32 | (12) | 4 | 363 | 246 | 239 | (118) | 6 | 552 | - | 552 | - | - | 313 |
| Air Vehicle Systems | 5 | 7 | 8 | 2 | (1) | 40 | 48 | 44 | 8 | 4 | 60 | - | 60 | - | - | 16 |
| **Build Team** | **25** | **24** | **7** | **(1)** | **17** | **75** | **74** | **22** | **(1)** | **52** | **150** | - | **150** | - | **-** | **128** |
| **Mission Sys & SW** | **3,052** | **2,781** | **1,514** | **(271)** | **1,267** | **12,358** | **12,081** | **7,825** | **(277)** | **4,256** | **23,395** | - | **23,060** | (40) | **335** | **15,235** |
| Avionics Seit | 952 | 923 | 354 | (29) | 569 | 4,032 | 3,811 | 2,093 | (221) | 1,719 | 7,182 | - | 7,068 | (13) | 114 | 4,976 |
| Core Processing | 742 | 749 | 436 | 7 | 313 | 3,316 | 3,248 | 1,938 | (68) | 1,310 | 5,197 | - | 4,985 | (25) | 212 | 3,047 |
| CNI | 82 | 24 | 20 | (58) | 4 | 268 | 211 | 130 | (57) | 81 | 520 | - | 520 | - | - | 390 |
| Display Prod | 64 | 4 | 3 | (60) | 1 | 82 | 19 | 26 | (63) | (7) | 273 | - | 273 | - | - | 247 |
| Electronic Warfare | 175 | 175 | 0 | - | 175 | 184 | 184 | 1 | - | 183 | 724 | - | 725 | 1 | (1) | 724 |
| Mission Avionics Software | 372 | 312 | 251 | (60) | 61 | 1,569 | 1,567 | 1,426 | (2) | 141 | 2,750 | - | 2,750 | - | - | 1,324 |
| Radar | 324 | 324 | 280 | - | 44 | 1,757 | 1,757 | 1,421 | - | 336 | 4,412 | - | 4,402 | (3) | 10 | 2,981 |
| Stores Mgmt Sys | 341 | 270 | 170 | (71) | 100 | 1,150 | 1,284 | 791 | 134 | 493 | 2,337 | - | 2,337 | - | - | 1,546 |
| **Sustainment & Mods** | **646** | **637** | **615** | **(9)** | **22** | **1,591** | **1,573** | **1,221** | **(18)** | **352** | **4,553** | - | **4,503** | (7) | **50** | **3,282** |
| Mods & Heavy Maint | 1 | 1 | - | - | 1 | 7 | 7 | - | - | 7 | 11 | - | 11 | - | - | 11 |
| Support Equipment | 13 | 10 | 2 | (3) | 8 | 103 | 97 | 44 | (6) | 53 | 154 | - | 153 | - | 1 | 109 |
| Support Services | 4 | 4 | 3 | - | 1 | 24 | 24 | 26 | - | (2) | 39 | - | 39 | - | - | 13 |
| Support Data & Int Main IS | 16 | 10 | 79 | (6) | (69) | 115 | 103 | 303 | (12) | (200) | 178 | - | 178 | - | - | (125) |
| Training | 612 | 612 | 531 | - | 81 | 1,341 | 1,341 | 848 | - | 493 | 4,171 | - | 4,122 | (7) | 49 | 3,274 |
| **Weapon System I&T** | **146** | **100** | **97** | **(46)** | **3** | **574** | **580** | **599** | **6** | **(19)** | **934** | - | **928** | (2) | **6** | **329** |
| Flight Test | 41 | 41 | 6 | - | 35 | 89 | 89 | 23 | - | 66 | 124 | - | 120 | (1) | 4 | 97 |
| FTS Instr | 12 | 11 | 24 | (1) | (13) | 93 | 92 | 124 | (1) | (32) | 129 | - | 129 | - | - | 5 |
| Test Plan & Supt | 89 | 44 | 67 | (45) | (23) | 372 | 379 | 451 | 7 | (72) | 651 | - | 651 | - | - | 200 |
| System Integ | 4 | 4 | - | - | 4 | 20 | 20 | - | - | 20 | 30 | - | 28 | (1) | 2 | 28 |
| **Program Operations** | **425** | **425** | **347** | **-** | **78** | **2,057** | **2,057** | **1,190** | **-** | **867** | **6,161** | - | **6,554** | 50 | **(393)** | **5,364** |
| **Modernization** | **84** | **82** | **28** | **(2)** | **54** | **904** | **902** | **123** | **(2)** | **779** | **1,248** | - | **1,248** | - | **0** | **1,125** |

| | BAC | $\Delta_{prev\ mth}$ | LRE | $\Delta_{prev\ mth}$ | VAC |
|---|---|---|---|---|---|
| **UB** | **3,990** | - | **3,990** | - | **-** |
| **MR** | **4,999** | - | **4,999** | - | **-** |
| **TOTAL** | **46,043** | - | **46,044** | 1 | **(1)** |

**Contract Budget Base** 46,043

**Delta** 0

Notes

At this point, the project was behind schedule by $402K and undercost by $6.3M, continuing a trend of growing underrun suggesting errors wrt the current PMB.

The BAC and LRE remained constant from last period, with funds shifting b/t Mission Sys & SW and Program Operations.

Data lacks verification past whole-number values; thus, rounding errors have occurred.

SPIRAL 2 PHASE B: EV DATA

October 2004

(000s)

| | CURRENT PERIOD | | | | | CUMULATIVE TO DATE | | | | | AT COMPLETION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BCWS | BCWP | ACWP | SV | CV | BCWS | BCWP | ACWP | SV | CV | BAC | $\Delta_{prev\ mth}$ | LRE | $\Delta_{prev\ mth}$ | VAC | $ETC_{LRE}$ |
| **F-22 Modernization REDI DO0002** | **4,054** | **3,454** | **2,996** | **(600)** | **458** | **22,017** | **21,015** | **14,260** | **(1,002)** | **6,755** | **36,850** | **(204)** | **36,725** | **(330)** | **125** | **22,465** |
| **Air Vehicle** | **60** | **114** | **57** | **54** | **57** | **464** | **408** | **340** | **(56)** | **67** | **601** | **(11)** | **489** | **(123)** | **112** | **149** |
| Air Vehicle Seit | 54 | 110 | 47 | 56 | 63 | 417 | 356 | 286 | (62) | 69 | 542 | (10) | 433 | (119) | 109 | 147 |
| Air Vehicle Systems | 6 | 4 | 10 | (2) | (6) | 46 | 52 | 54 | 6 | (2) | 59 | (1) | 56 | (4) | 3 | 2 |
| **Build Team** | **24** | **24** | **8** | **-** | **16** | **99** | **98** | **30** | **(1)** | **68** | **146** | **(4)** | **131** | **(19)** | **15** | **101** |
| **Mission Sys & SW** | **3,014** | **2,679** | **1,665** | **(335)** | **1,014** | **15,372** | **14,760** | **9,490** | **(612)** | **5,270** | **23,247** | **(148)** | **22,262** | **(798)** | **985** | **12,772** |
| Avionics Seit | 928 | 894 | 387 | (34) | 507 | 4,960 | 4,705 | 2,480 | (255) | 2,226 | 7,146 | (36) | 6,558 | (510) | 588 | 4,079 |
| Core Processing | 639 | 545 | 387 | (94) | 158 | 3,955 | 3,793 | 2,325 | (162) | 1,468 | 5,197 | - | 4,985 | - | 212 | 2,660 |
| CNI | 88 | 32 | 13 | (56) | 19 | 356 | 243 | 143 | (113) | 100 | 515 | (5) | 457 | (63) | 58 | 314 |
| Display Prod | 63 | 7 | 6 | (56) | 1 | 145 | 26 | 32 | (119) | (6) | 273 | - | 276 | 3 | (3) | 244 |
| Electronic Warfare | 176 | 176 | - | - | 176 | 360 | 360 | 1 | - | 359 | 724 | - | 717 | (8) | 7 | 716 |
| Mission Avionics Software | 369 | 366 | 358 | (3) | 8 | 1,938 | 1,933 | 1,784 | (5) | 149 | 2,706 | (44) | 2,710 | (40) | (4) | 926 |
| Radar | 313 | 313 | 274 | - | 39 | 2,070 | 2,070 | 1,695 | - | 375 | 4,412 | - | 4,402 | - | 10 | 2,707 |
| Stores Mgmt Sys | 438 | 346 | 240 | (92) | 106 | 1,588 | 1,630 | 1,031 | 42 | 599 | 2,274 | (63) | 2,157 | (180) | 117 | 1,126 |
| **Sustainment & Mods** | **341** | **11** | **664** | **(330)** | **(653)** | **1,932** | **1,584** | **1,885** | **(348)** | **(301)** | **4,546** | **(7)** | **4,511** | **8** | **35** | **2,626** |
| Mods & Heavy Maint | 1 | 1 | - | - | 1 | 8 | 8 | - | - | 8 | 11 | - | 5 | (6) | 6 | 5 |
| Support Equipment | 11 | 9 | 5 | (2) | 4 | 114 | 106 | 49 | (8) | 57 | 151 | (3) | 118 | (35) | 33 | 69 |
| Support Services | 4 | 4 | 6 | - | (2) | 28 | 28 | 32 | - | (4) | 39 | - | 46 | 7 | (7) | 14 |
| Support Data & Int Main IS | 15 | 9 | 80 | (6) | (71) | 130 | 112 | 383 | (18) | (271) | 174 | (4) | 220 | 42 | (46) | (163) |
| Training | 310 | (12) | 573 | (322) | (585) | 1,651 | 1,329 | 1,421 | (322) | (92) | 4,171 | - | 4,122 | - | 49 | 2,701 |
| **Weapon System I&T** | **112** | **123** | **153** | **11** | **(30)** | **686** | **703** | **752** | **17** | **(49)** | **918** | **(16)** | **955** | **27** | **(37)** | **203** |
| Flight Test | 12 | 12 | 2 | - | 10 | 101 | 101 | 25 | - | 76 | 124 | - | 107 | (13) | 17 | 82 |
| FTS Instr | 14 | 14 | 40 | - | (26) | 107 | 106 | 164 | (1) | (58) | 127 | (2) | 111 | (18) | 16 | (53) |
| Test Plan & Supt | 82 | 93 | 111 | 11 | (18) | 454 | 472 | 562 | 18 | (90) | 637 | (14) | 709 | 58 | (72) | 147 |
| System Integ | 4 | 4 | - | - | 4 | 24 | 24 | - | - | 24 | 30 | - | 28 | - | 2 | 28 |
| **Program Operations** | **398** | **398** | **345** | **-** | **53** | **2,455** | **2,455** | **1,535** | **-** | **920** | **6,159** | **(2)** | **6,512** | **(42)** | **(353)** | **4,977** |
| **Modernization** | **105** | **105** | **104** | **-** | **1** | **1,009** | **1,007** | **227** | **(2)** | **780** | **1,233** | **(15)** | **1,865** | **617** | **(632)** | **1,638** |

| | BAC | $\Delta_{prev\ mth}$ | LRE | $\Delta_{prev\ mth}$ | VAC |
|---|---|---|---|---|---|
| **UB** | **3,779** | **(211)** | **3,779** | **(211)** | **-** |
| **MR** | **5,415** | **416** | **5,539** | **540** | **(124)** |
| **TOTAL** | **46,044** | **1** | **46,043** | **####** | **1** |

**Contract Budget Base** 46,043

**Delta** (1)

Notes

At this point, the project was behind schedule by $1M and undercost by $6.8M, continuing a trend of growing underrun suggesting errors wrt the current PMB.

The BAC, LRE and UB decreased from last period, with funds shifting to MR ostensibly due to lower OH rates.

Data lacks verification past whole-number values; thus, rounding errors have occurred.

SPIRAL 2 PHASE B: EV DATA

November 2004

(000s)

| | CURRENT PERIOD | | | | | CUMULATIVE TO DATE | | | | | AT COMPLETION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BCWS | BCWP | ACWP | SV | CV | BCWS | BCWP | ACWP | SV | CV | BAC | $\Delta_{prev\ mth}$ | LRE | $\Delta_{prev\ mth}$ | VAC | $ETC_{LRE}$ |
| **F-22 Modernization REDI DO0002** | **4,885** | **5,342** | **2,431** | **457** | **2,911** | **26,902** | **26,357** | **16,691** | **(545)** | **9,666** | **36,850** | - | **36,725** | - | **125** | **20,034** |
| **Air Vehicle** | **45** | **113** | **65** | **68** | **48** | **509** | **521** | **405** | **12** | **115** | **601** | - | **489** | - | **112** | **84** |
| Air Vehicle Seit | 41 | 114 | 57 | 73 | 57 | 458 | 470 | 343 | 11 | 126 | 542 | - | 433 | - | 109 | 90 |
| Air Vehicle Systems | 4 | (1) | 8 | (5) | (9) | 50 | 51 | 62 | 1 | (11) | 59 | - | 56 | - | 3 | (6) |
| **Build Team** | **24** | **24** | **6** | **-** | **18** | **123** | **122** | **36** | **(1)** | **86** | **146** | - | **131** | - | **15** | **95** |
| **Mission Sys & SW** | **3,377** | **3,705** | **1,345** | **328** | **2,360** | **18,749** | **18,465** | **10,835** | **(284)** | **7,630** | **23,247** | - | **22,228** | (34) | **1,019** | **11,393** |
| Avionics Seit | 916 | 1,159 | 366 | 243 | 793 | 5,876 | 5,864 | 2,846 | (12) | 3,019 | 7,146 | - | 6,545 | (13) | 601 | 3,700 |
| Core Processing | 622 | 709 | 356 | 87 | 353 | 4,577 | 4,502 | 2,681 | (75) | 1,821 | 5,197 | - | 4,966 | (19) | 231 | 2,285 |
| CNI | 79 | 81 | 13 | 2 | 68 | 435 | 324 | 156 | (111) | 168 | 515 | - | 457 | - | 58 | 301 |
| Display Prod | 64 | 61 | 5 | (3) | 56 | 209 | 87 | 37 | (122) | 50 | 273 | - | 276 | - | (3) | 239 |
| Electronic Warfare | 175 | 175 | - | - | 175 | 535 | 535 | 1 | - | 534 | 724 | - | 717 | - | 7 | 716 |
| Mission Avionics Software | 389 | 389 | 252 | - | 137 | 2,327 | 2,322 | 2,036 | (5) | 286 | 2,706 | - | 2,710 | - | (4) | 674 |
| Radar | 798 | 839 | 162 | 41 | 677 | 2,868 | 2,909 | 1,857 | 41 | 1,052 | 4,412 | - | 4,400 | (2) | 12 | 2,543 |
| Stores Mgmt Sys | 334 | 292 | 191 | (42) | 101 | 1,922 | 1,922 | 1,222 | - | 700 | 2,274 | - | 2,157 | - | 117 | 935 |
| **Sustainment & Mods** | **831** | **908** | **535** | **77** | **373** | **2,763** | **2,492** | **2,420** | **(271)** | **71** | **4,546** | - | **4,503** | (8) | **43** | **2,083** |
| Mods & Heavy Maint | 1 | 1 | 0 | - | 1 | 9 | 9 | 0 | - | 9 | 11 | - | 5 | - | 6 | 5 |
| Support Equipment | 11 | 9 | 11 | (2) | (2) | 125 | 115 | 60 | (10) | 55 | 151 | - | 118 | - | 33 | 58 |
| Support Services | 5 | 5 | 5 | - | - | 33 | 33 | 37 | - | (4) | 39 | - | 46 | - | (7) | 9 |
| Support Data & Int Main IS | 15 | 9 | 80 | (6) | (71) | 145 | 121 | 463 | (24) | (342) | 174 | - | 220 | - | (46) | (243) |
| Training | 799 | 884 | 439 | 85 | 445 | 2,450 | 2,213 | 1,860 | (237) | 353 | 4,171 | - | 4,114 | (8) | 57 | 2,254 |
| **Weapon System I&T** | **105** | **89** | **124** | **(16)** | **(35)** | **791** | **792** | **875** | **1** | **(83)** | **918** | - | **955** | - | **(37)** | **80** |
| Flight Test | 11 | 11 | (0) | - | 11 | 112 | 112 | 25 | - | 87 | 124 | - | 107 | - | 17 | 82 |
| FTS Instr | 10 | 10 | 41 | - | (31) | 117 | 116 | 205 | (1) | (89) | 127 | - | 111 | - | 16 | (94) |
| Test Plan & Supt | 81 | 65 | 83 | (16) | (18) | 535 | 537 | 645 | 2 | (108) | 637 | - | 709 | - | (72) | 64 |
| System Integ | 3 | 3 | - | - | 3 | 27 | 27 | - | - | 27 | 30 | - | 28 | - | 2 | 28 |
| **Program Operations** | **384** | **384** | **292** | **-** | **92** | **2,839** | **2,839** | **1,827** | **-** | **1,012** | **6,159** | - | **6,554** | 42 | **(395)** | **4,727** |
| **Modernization** | **119** | **119** | **64** | **-** | **55** | **1,128** | **1,126** | **291** | **(2)** | **835** | **1,233** | - | **1,865** | - | **(632)** | **1,574** |
| | | | | | | | | | | **UB** | **3,779** | - | **3,779** | - | **-** | |
| | | | | | | | | | | **MR** | **5,415** | - | **5,539** | - | **(124)** | |
| | | | | | | | | | | **TOTAL** | **46,044** | - | **46,043** | - | **1** | |

**Contract Budget Base** 46,043

**Delta** (1)

Notes

At this point, the project was behind schedule by $545K and undercost by $9.7M, continuing a trend of growing underrun suggesting errors wrt the current PMB.

The BAC and LRE remained constant from last period, with funds shifting b/t Mission Sys & SW and Program Operations w/i LRE (2nd time).

Data lacks verification past whole-number values; thus, rounding errors have occurred.

SPIRAL 2 PHASE B: EV DATA

December 2004

(000s)

| | CURRENT PERIOD | | | | | CUMULATIVE TO DATE | | | | | AT COMPLETION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BCWS | BCWP | ACWP | SV | CV | BCWS | BCWP | ACWP | SV | CV | BAC | $\Delta_{prev\ mth}$ | LRE | $\Delta_{prev\ mth}$ | VAC | $ETC_{LRE}$ |
| **F-22 Modernization REDI DO0002** | **6,338** | **6,002** | **2,623** | **(336)** | **3,379** | **33,240** | **32,359** | **19,314** | **(881)** | **13,044** | **36,850** | - | **36,726** | 1 | **124** | **17,412** |
| **Air Vehicle** | **96** | **78** | **61** | **(18)** | **17** | **605** | **599** | **466** | **(6)** | **132** | **601** | - | **489** | - | **112** | **23** |
| Air Vehicle Seit | 87 | 73 | 52 | (14) | 21 | 545 | 543 | 395 | (3) | 147 | 542 | - | 433 | - | 109 | 38 |
| Air Vehicle Systems | 9 | 5 | 9 | (4) | (4) | 59 | 56 | 71 | (3) | (15) | 59 | - | 56 | - | 3 | (15) |
| **Build Team** | **24** | **24** | **8** | - | **16** | **147** | **146** | **44** | **(1)** | **102** | **146** | - | **131** | - | **15** | **87** |
| **Mission Sys & SW** | **3,365** | **3,206** | **1,381** | **(159)** | **1,825** | **22,114** | **21,671** | **12,217** | **(443)** | **9,454** | **23,247** | - | **22,022** | (206) | **1,225** | **9,805** |
| Avionics Seit | 1,282 | 1,228 | 403 | (54) | 825 | 7,158 | 7,092 | 3,249 | (66) | 3,844 | 7,146 | - | 6,486 | (59) | 660 | 3,238 |
| Core Processing | 622 | 696 | 265 | 74 | 431 | 5,199 | 5,198 | 2,946 | (1) | 2,252 | 5,197 | - | 4,842 | (124) | 355 | 1,896 |
| CNI | 81 | 80 | 9 | (1) | 71 | 516 | 404 | 165 | (112) | 239 | 515 | - | 457 | - | 58 | 292 |
| Display Prod | 62 | 62 | 11 | - | 51 | 271 | 149 | 48 | (122) | 101 | 273 | - | 276 | - | (3) | 228 |
| Electronic Warfare | 189 | 176 | 0 | (13) | 176 | 724 | 711 | 1 | (13) | 710 | 724 | - | 717 | - | 7 | 716 |
| Mission Avionics Software | 397 | 383 | 305 | (14) | 78 | 2,724 | 2,705 | 2,341 | (19) | 364 | 2,706 | - | 2,710 | - | (4) | 369 |
| Radar | 373 | 228 | 177 | (145) | 51 | 3,241 | 3,137 | 2,034 | (104) | 1,103 | 4,412 | - | 4,377 | (23) | 35 | 2,343 |
| Stores Mgmt Sys | 359 | 353 | 211 | (6) | 142 | 2,281 | 2,275 | 1,433 | (6) | 842 | 2,274 | - | 2,157 | - | 117 | 724 |
| **Sustainment & Mods** | **1,787** | **1,658** | **409** | **(129)** | **1,249** | **4,550** | **4,150** | **2,830** | **(400)** | **1,320** | **4,546** | - | **4,474** | (29) | **72** | **1,644** |
| Mods & Heavy Maint | 1 | 1 | 0 | - | 1 | 10 | 10 | 1 | - | 10 | 11 | - | 5 | - | 6 | 4 |
| Support Equipment | 27 | 8 | 10 | (19) | (2) | 152 | 123 | 70 | (29) | 53 | 151 | - | 118 | - | 33 | 48 |
| Support Services | 5 | 5 | 9 | - | (4) | 38 | 38 | 46 | - | (8) | 39 | - | 46 | - | (7) | - |
| Support Data & Int Main IS | 32 | 6 | 20 | (26) | (14) | 177 | 127 | 483 | (50) | (356) | 174 | - | 220 | - | (46) | (263) |
| Training | 1,722 | 1,638 | 370 | (84) | 1,268 | 4,172 | 3,851 | 2,230 | (321) | 1,621 | 4,171 | - | 4,085 | (29) | 86 | 1,855 |
| **Weapon System I&T** | **129** | **99** | **140** | **(30)** | **(41)** | **920** | **891** | **1,015** | **(29)** | **(124)** | **918** | - | **953** | (2) | **(35)** | **(62)** |
| Flight Test | 11 | 11 | (0) | - | 11 | 123 | 123 | 25 | - | 98 | 124 | - | 105 | (2) | 19 | 80 |
| FTS Instr | 11 | 11 | 45 | - | (34) | 128 | 127 | 250 | (1) | (123) | 127 | - | 111 | - | 16 | (139) |
| Test Plan & Supt | 104 | 74 | 95 | (30) | (21) | 639 | 611 | 740 | (28) | (129) | 637 | - | 709 | - | (72) | (31) |
| System Integ | 3 | 3 | - | - | 3 | 30 | 30 | - | - | 30 | 30 | - | 28 | - | 2 | 28 |
| **Program Operations** | **798** | **798** | **555** | - | **243** | **3,637** | **3,637** | **2,382** | - | **1,255** | **6,159** | - | **6,792** | 238 | **(633)** | **4,410** |
| **Modernization** | **139** | **139** | **69** | - | **70** | **1,267** | **1,265** | **360** | **(2)** | **905** | **1,233** | - | **1,865** | - | **(632)** | **1,505** |

| | BAC | $\Delta_{prev\ mth}$ | LRE | $\Delta_{prev\ mth}$ | VAC |
|---|---|---|---|---|---|
| **UB** | **3,780** | 1 | **3,779** | - | **1** |
| **MR** | **5,415** | - | **5,539** | - | **(124)** |
| **TOTAL** | **46,045** | 1 | **46,044** | 1 | **1** |

**Contract Budget Base** 46,043

**Delta** (2)

Notes

At this point, the project was behind schedule by $881K and undercost by $13M, continuing a trend of growing underrun suggesting errors wrt the current PMB.

The BAC and LRE remained constant from last period, with funds shifting b/t Mission Sys & SW and Program Operations w/i LRE (3rd time).

Data lacks verification past whole-number values; thus, rounding errors have occurred.

SPIRAL 2 PHASE B: EV DATA

January 2004

(000s)

| | CURRENT PERIOD | | | | | CUMULATIVE TO DATE | | | | | AT COMPLETION | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BCWS | BCWP | ACWP | SV | CV | BCWS | BCWP | ACWP | SV | CV | BAC | $\Delta_{prev\ mth}$ | LRE | $\Delta_{prev\ mth}$ | VAC | $ETC_{LRE}$ |
| **F-22 Modernization REDI DO0002** | **345** | **644** | **2,912** | **299** | **(2,268)** | **33,585** | **33,003** | **22,226** | **(582)** | **10,776** | **36,799** | (51) | **36,688** | (38) | **111** | **14,462** |
| **Air Vehicle** | - | **40** | **42** | **40** | **(2)** | **605** | **639** | **508** | **34** | **130** | **601** | - | **489** | - | **112** | **(19)** |
| Air Vehicle Seit | - | 38 | 32 | 38 | 6 | 545 | 581 | 427 | 35 | 153 | 542 | - | 433 | - | 109 | 6 |
| Air Vehicle Systems | - | 2 | 10 | 2 | (8) | 59 | 58 | 81 | (1) | (23) | 59 | - | 56 | - | 3 | (25) |
| **Build Team** | - | - | **27** | - | **(27)** | **147** | **146** | **71** | **(1)** | **75** | **146** | - | **131** | - | **15** | **60** |
| **Mission Sys & SW** | **345** | **597** | **1,473** | **252** | **(876)** | **22,459** | **22,268** | **13,690** | **(191)** | **8,578** | **23,319** | 72 | **22,080** | 58 | **1,239** | **8,390** |
| Avionics Seit | - | 52 | 392 | 52 | (340) | 7,158 | 7,144 | 3,641 | (14) | 3,504 | 7,146 | - | 6,486 | - | 660 | 2,846 |
| Core Processing | - | - | 404 | - | (404) | 5,199 | 5,198 | 3,350 | (1) | 1,848 | 5,197 | - | 4,842 | - | 355 | 1,492 |
| CNI | - | 1 | 4 | 1 | (3) | 516 | 405 | 169 | (111) | 236 | 515 | - | 457 | - | 58 | 288 |
| Display Prod | - | - | 4 | - | (4) | 271 | 149 | 52 | (122) | 97 | 273 | - | 276 | - | (3) | 224 |
| Electronic Warfare | - | - | - | - | - | 724 | 711 | 1 | (13) | 710 | 724 | - | 717 | - | 7 | 716 |
| Mission Avionics Software | - | 95 | 293 | 95 | (198) | 2,724 | 2,800 | 2,634 | 76 | 166 | 2,706 | - | 2,710 | - | (4) | 76 |
| Radar | 345 | 449 | 162 | 104 | 287 | 3,586 | 3,586 | 2,196 | - | 1,390 | 4,484 | 72 | 4,435 | 58 | 49 | 2,239 |
| Stores Mgmt Sys | - | - | 214 | - | (214) | 2,281 | 2,275 | 1,647 | (6) | 628 | 2,274 | - | 2,157 | - | 117 | 510 |
| **Sustainment & Mods** | - | - | **921** | - | **(921)** | **4,550** | **4,150** | **3,751** | **(400)** | **399** | **4,546** | - | **4,481** | 7 | **65** | **730** |
| Mods & Heavy Maint | - | - | - | - | - | 10 | 10 | 1 | - | 10 | 11 | - | 5 | - | 6 | 4 |
| Support Equipment | - | - | 10 | - | (10) | 152 | 123 | 80 | (29) | 43 | 151 | - | 118 | - | 33 | 38 |
| Support Services | - | - | 6 | - | (6) | 38 | 38 | 52 | - | (14) | 39 | - | 46 | - | (7) | (6) |
| Support Data & Int Main IS | - | - | 182 | - | (182) | 177 | 127 | 665 | (50) | (538) | 174 | - | 220 | - | (46) | (445) |
| Training | - | - | 723 | - | (723) | 4,172 | 3,851 | 2,953 | (321) | 898 | 4,171 | - | 4,092 | 7 | 79 | 1,139 |
| **Weapon System I&T** | - | **7** | **57** | **7** | **(50)** | **920** | **898** | **1,072** | **(22)** | **(174)** | **794** | (124) | **848** | (105) | **(54)** | **(224)** |
| Flight Test | - | - | - | - | - | 123 | 123 | 25 | - | 98 | - | (124) | - | (105) | - | (25) |
| FTS Instr | - | - | 33 | - | (33) | 128 | 127 | 283 | (1) | (156) | 127 | - | 111 | - | 16 | (172) |
| Test Plan & Supt | - | 7 | 24 | 7 | (17) | 639 | 618 | 764 | (21) | (146) | 637 | - | 709 | - | (72) | (55) |
| System Integ | - | - | - | - | - | 30 | 30 | - | - | 30 | 30 | - | 28 | - | 2 | 28 |
| **Program Operations** | - | - | **353** | - | **(353)** | **3,637** | **3,637** | **2,735** | - | **902** | **6,160** | 1 | **6,794** | 2 | **(634)** | **4,059** |
| **Modernization** | - | - | **39** | - | **(39)** | **1,267** | **1,265** | **399** | **(2)** | **866** | **1,233** | - | **1,865** | - | **(632)** | **1,466** |

| | BAC | $\Delta_{prev\ mth}$ | LRE | $\Delta_{prev\ mth}$ | VAC |
|---|---|---|---|---|---|
| **UB** | **3,780** | - | **3,779** | - | **1** |
| **MR** | **5,415** | - | **5,539** | - | **(124)** |
| **TOTAL** | **45,994** | (51) | **46,006** | (38) | **(12)** |

| | |
|---|---|
| **Contract Budget Base** | **46,043** |
| **Delta** | **49** |
| **Management EAC** | **21,047** |
| **Delta** | **24,947** |

Notes

At this point, the project was behind schedule by $582K and undercost by $11M, partly explained by the definitized EAC and target budget of $21M instead of the previous $46M.

The BAC and LRE decreased slightly from last period, due to realignment w/i Weapon System I&T.

Data lacks verification past whole-number values; thus, rounding errors have occurred.

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# APPENDIX B – EVM QUESTIONNAIRE

*Please answer the following questions by **circling** your selection.*

**QUESTION #1** Using the options provided below, circle the function that best describes your current role within the F-22 program:

Government Employee

| Contract Manager | Engineer | Financial Manager | Program Manager | Other |
|---|---|---|---|---|

Contractor Employee

| Contract Manager | Engineer | Financial Manager | Program Manager | Other |
|---|---|---|---|---|

Other: ________________________________________

**QUESTION #2** Using the options provided below, identify the areas within the F-22 program you have working knowledge of **(circle all that apply)**:

| Airframe | Avionics | Support Systems | Propulsion | Other |
|---|---|---|---|---|

Other: ________________________________________

| EMD | Modernization | Production | Sustainment | Other |
|---|---|---|---|---|

Other: ________________________________________

**QUESTION #3** Using the scale provided below, identify how often you use or are exposed to some form of EVMS:

| Never | Once per Month | More Than Once per Month | Once per Week | More Than Once per Week |
|---|---|---|---|---|

**QUESTION #4** Using the options provided below, identify which best describes how you utilize your program's EVM information:

| Reporting Tool Only | Reporting Tool with (some) Management Uses | Equal Parts Reporting and Management Tool | Management Tool with (some) Reporting Uses | Management Tool Only |
|---|---|---|---|---|

**QUESTION #5** Using the options provided below, please assess the value of your program's EVM *information*:

1 2 3 4 5

Very Little Value → Very High Value

**QUESTION #6** Using the scale provided below, please self-assess your knowledge of EVM:

1 2 3 4 5

What's EVM, again? → I am an EVM master!

**QUESTION #7** Are you aware of the 32 criteria set forth by ANSI/EIA-748 for assessing Earned Value Management Systems?

YES NO

If you answered "**YES**", please proceed to <u>question **#8**</u>.

If you answered "**NO**", please proceed to <u>question **#9**</u>.

**QUESTION #8** Do you think your program implements its EVMS according to the 32 ANSI/EIA-748 Earned Value Management System criteria?

YES NO

**QUESTION #9** Using the options provided below, please describe the usefulness of your program's EVMS:

1 2 3 4 5

Not at All Useful → Very Useful

# APPENDIX C – EVM QUESTIONNAIRE RESULTS

## A. RAW QUESTIONNAIRE RESPONSE DATA

| Q | Focus | Potential Responses | Actual Responses | | | | | | | | | | | | | | | | | | | | | | | | | | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 14 | 7 | 8 | 15 | 11 | 9 | 12 | 1 | 4 | 2<br>Incomplete Response | 3 | 6 | 17 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | |
| 1 | Function | Govt K Mngr | | | | | | | | | | | | | | | | | | | | | | | |1| | | 1 |
| | | Govt Eng | | | | | | | |1|1| |1|1| | | | | | | | | | | | |1| | 5 |
| | | Govt FM |1|1|1|1| |1| | | | | | | | | | | | |1| | | |1| | | | 7 |
| | | Govt PM | | | | | | |1| | | | | |1|1| | | | | | | | | | | | | 3 |
| | | Govt Other | | | | |1| | | | | | | | | | | | | | | | | | | | | | 1 |
| | | Ktr K Mngr | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| | | Ktr Eng | | | | | | | | | | | | | | |1|1| |1| | |1| | | | | | 4 |
| | | Ktr FM | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| | | Ktr PM | | | | | | | | | | | | | | | | |1| | |1| |1| | | |1| 4 |
| | | Ktr Other | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| 2 | Area | Airframe | | | | |1|1| | | | | | | |1| | | | |1| | | | |1| |1| 6 |
| | | Avionics | |1|1| |1|1|1|1|1| |1|1|1|1|1| |1|1|1|1|1|1| |1|1|1| 21 |
| | | Support | |1|1| | | | |1| | | | | |1|1|1| |1|1|1| |1| | | |1| 11 |
| | | Propulsion | | | | | | | |1| | | | | |1| | | | | | | | |1| | | | 3 |
| | | Other | |1| |1| | | | | | | | | | | | | | | | | | | | | | | 2 |
| | | EMD | |1| |1| |1| |1| | |1|1| | |1| |1|1|1| |1| | |1|1|1| 14 |
| | | Mod |1|1|1|1|1|1|1|1| | |1|1|1| |1|1|1|1|1|1|1|1| |1|1|1| 22 |
| | | Prod | | | |1|1|1| | | | | |1| |1|1| | | |1| | | |1|1| |1| 10 |
| | | Sust | |1| |1| | | | | | | |1| |1|1|1| | |1| | |1| | | |1| 9 |
| | | Other | | | |1| | | | | | | | | | | | | | | | | | | | | | | 1 |
| 3 | Frequency | Never | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| | | Once per Mo | | | | |1| |1|1|1| |1| | |1| | | | | | | | |1|1|1| | 9 |
| | | More than 1/Mo |1|1| |1| | | | | | | |1|1| | |1| | |1| | | | | | | | 7 |
| | | Once per Wk | | |1| | |1| | | | | | | | |1| | |1| |1|1| | | | |1| 7 |
| | | More than 1/Wk | | | | | | | | | | | | | | | | |1| | | | |1| | | | | 2 |
| 4 | Method of Use | Report Only | | | | | | | | |1| |1| | | | | | | | | | | | | | | | 2 |
| | | Report & Some Manage |1| | |1| | | |1| | | |1| |1| |1| |1|1| | | | |1| | | 9 |
| | | Report/Manage | |1|1| | |1| | | | | | | | | | |1| | |1|1|1| | |1| | 8 |
| | | Manage & Some Report | | | | |1| |1| | | | | |1| | | | | | | | | | | | |1| 4 |
| | | Manage Only | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| 5 | Value | 1 (Very Little) | | | | | | | | | | |1| |1| | |1| | | | | | | |1| | | 4 |
| | | 2 | | | | |1| | |1|1| | | | |1| | | | | | | | | | | | | 4 |
| | | 3 | | | |1| | | | | | | |1| | |1| | |1| |1| |1|1| |1|1| 9 |
| | | 4 |1|1| | | |1|1| | | | | | | | | |1| |1| |1| | | | | | 7 |
| | | 5 (Very High) | | |1| | | | | | | | | | | | | | | | | | | | | | | | 1 |
| 6 | Knowledge | 1 (??) | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| | | 2 |1| | | | | | | | | | | | | | | | |1| | | | |1|1|1| | 5 |
| | | 3 | | |1| | | |1| |1| |1|1| | |1|1| | |1| |1| | | | | | 9 |
| | | 4 | |1| | |1|1| |1| | | | |1|1| | |1| | |1| |1| | | |1| 10 |
| | | 5 (Master) | | | |1| | | | | | | | | | | | | | | | | | | | | | | 1 |
| 7 | 32 Criteria | Yes | |1|1|1| | |1| | | | | | | | | | | | |1| | | | | |1| 6 |
| | | No |1| | | |1|1| |1|1| |1|1|1|1|1|1|1|1|1| |1|1|1|1|1| | 19 |
| 8 | Criteria Implementation | Yes | |1|1|1| | |1| | | | | | | | | | | | |1| | | | | |1| 6 |
| | | No | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| 9 | Usefulness | 1 (Not) | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 |
| | | 2 | | | | |1| | |1|1| | | |1|1| |1| | | | | | |1|1| | | 8 |
| | | 3 | | | |1| | | | | | |1|1| | |1| |1|1| |1| |1| | |1| | 9 |
| | | 4 |1|1| | | |1|1| | | | | | | | | | | |1| |1| | | | |1| 7 |
| | | 5 (Very) | | |1| | | | | | | | | | | | | | | | | | | | | | | | 1 |

# B. QUESTIONNAIRE STATISTICAL ANALYSIS RESULTS

| | Frequency | Method of Use | Value | Knowledge | 32 Criteria | Criteria Implementation | Usefulness |
|---|---|---|---|---|---|---|---|
| Sample Mean | 3.1 | 2.6 | 2.9 | 3.3 | 1.8 | 1.0 | 3.0 |
| Equivalent Response | More than 1/Mo | Report/Manage | 3.0 | 3.0 | No | Yes | 3.0 |
| Sample S.D. | 1.00 | 0.89 | 1.13 | 0.84 | 0.44 | 0.00 | 0.89 |

By Function, All

| | | % of | Frequency | | Method of Use | | Value | | Knowledge | | 32 Criteria | | Criteria Implementation | | Usefulness | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Respondents | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. |
| Contract Manager | 1 | 4% | 2.0 | 0.00 | 2.0 | 0.00 | 1.0 | 0.00 | 2.0 | 0.00 | 2.0 | 0.00 | #DIV/0! | 0.00 | 2.0 | 0.00 |
| Engineer | 9 | 36% | 2.9 | 0.9 | 2.0 | 0.8 | 2.4 | 1.0 | 2.9 | 0.6 | 2.0 | 0.0 | #DIV/0! | #DIV/0! | 2.8 | 0.7 |
| Financial Manager | 7 | 28% | 3.1 | 0.7 | 2.5 | 0.5 | 3.9 | 0.7 | 3.3 | 1.1 | 1.6 | 0.5 | 1.0 | 0.0 | 3.7 | 1.0 |
| Program Manager | 7 | 28% | 3.6 | 1.3 | 3.3 | 0.8 | 2.9 | 1.1 | 3.9 | 0.4 | 1.6 | 0.5 | 1.0 | 0.0 | 3.0 | 0.8 |
| Other | 1 | 4% | 2.0 | 0.00 | 4.0 | 0.00 | 2.0 | 0.00 | 4.0 | 0.00 | 2.0 | 0.00 | #DIV/0! | 0.00 | 2.0 | 0.00 |

By Function, Government

| | | % of | Frequency | | Method of Use | | Value | | Knowledge | | 32 Criteria | | Criteria Implementation | | Usefulness | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Respondents | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. |
| Contract Manager | 1 | 4% | 2.0 | 0.00 | 2.0 | 0.00 | 1.0 | 0.00 | 2.0 | 0.00 | 2.0 | 0.00 | #DIV/0! | 0.00 | 2.0 | 0.00 |
| Engineer | 5 | 20% | 2.2 | 0.4 | 1.8 | 0.8 | 2.2 | 0.8 | 3.0 | 0.7 | 2.0 | 0.0 | #DIV/0! | #DIV/0! | 2.6 | 0.5 |
| Financial Manager | 7 | 28% | 3.1 | 0.7 | 2.5 | 0.5 | 3.9 | 0.7 | 3.3 | 1.1 | 1.6 | 0.5 | 1.0 | 0.0 | 3.7 | 1.0 |
| Program Manager | 3 | 12% | 2.3 | 0.6 | 3.3 | 1.2 | 2.3 | 1.5 | 3.7 | 0.6 | 1.7 | 0.6 | 1.0 | #DIV/0! | 2.7 | 1.2 |
| Other | 1 | 4% | 2.0 | 0.00 | 4.0 | 0.00 | 2.0 | 0.00 | 4.0 | 0.00 | 2.0 | 0.00 | #DIV/0! | 0.00 | 2.0 | 0.00 |

By Function, Contractor

| | | % of | Frequency | | Method of Use | | Value | | Knowledge | | 32 Criteria | | Criteria Implementation | | Usefulness | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Respondents | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. |
| Contract Manager | 0 | 0% | | | | | | | | | | | | | | |
| Engineer | 4 | 16% | 3.8 | 0.5 | 2.3 | 0.6 | 2.8 | 1.3 | 2.8 | 0.5 | 2.0 | 0.0 | #DIV/0! | #DIV/0! | 3.0 | 0.8 |
| Financial Manager | 0 | 0% | | | | | | | | | | | | | | |
| Program Manager | 4 | 16% | 4.5 | 0.6 | 3.3 | 0.5 | 3.3 | 0.5 | 4.0 | 0.0 | 1.5 | 0.6 | 1.0 | 0.0 | 3.3 | 0.5 |
| Other | 0 | 0% | | | | | | | | | | | | | | |

By Area, All

| | | % of | Frequency | | Method of Use | | Value | | Knowledge | | 32 Criteria | | Criteria Implementation | | Usefulness | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Respondents | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. |
| Airframe | 6 | 24% | 2.8 | 0.98 | 2.8 | 0.98 | 2.7 | 1.21 | 3.5 | 0.84 | 1.8 | 0.41 | 1.0 | #DIV/0! | 3.0 | 1.10 |
| Avionics | 21 | 84% | 3.1 | 1.1 | 2.7 | 0.9 | 2.9 | 1.1 | 3.3 | 0.7 | 1.8 | 0.4 | 1.0 | 0.0 | 3.1 | 0.9 |
| Support | 11 | 44% | 3.5 | 0.9 | 2.6 | 0.7 | 3.0 | 1.1 | 3.5 | 0.7 | 1.6 | 0.5 | 1.0 | 0.0 | 3.2 | 1.0 |
| Propulsion | 3 | 12% | 2.0 | 0.0 | 2.0 | 0.0 | 2.3 | 0.6 | 3.3 | 1.2 | 2.0 | 0.0 | #DIV/0! | #DIV/0! | 2.0 | 0.0 |
| Other | 2 | 8% | 3.0 | 0.00 | 2.5 | 0.71 | 3.5 | 0.71 | 4.5 | 0.71 | 1.0 | 0.00 | 1.0 | 0.00 | 3.5 | 0.71 |

By Area, All

| | | % of | Frequency | | Method of Use | | Value | | Knowledge | | 32 Criteria | | Criteria Implementation | | Usefulness | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Respondents | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. |
| EMD | 14 | 56% | 3.2 | 0.97 | 2.5 | 0.78 | 3.0 | 1.04 | 3.3 | 0.91 | 1.8 | 0.43 | 1.0 | 0.00 | 3.2 | 0.70 |
| Mod | 22 | 88% | 3.2 | 1.0 | 2.7 | 0.8 | 3.0 | 1.2 | 3.3 | 0.8 | 1.7 | 0.5 | 1.0 | 0.0 | 3.2 | 0.9 |
| Prod | 10 | 40% | 2.9 | 0.9 | 2.6 | 0.9 | 2.8 | 0.9 | 3.4 | 1.0 | 1.8 | 0.4 | 1.0 | 0.0 | 2.9 | 0.9 |
| Sust | 9 | 36% | 3.3 | 0.9 | 2.5 | 0.8 | 2.9 | 0.9 | 3.7 | 0.7 | 1.7 | 0.5 | 1.0 | 0.0 | 3.1 | 0.8 |
| Other | 1 | 4% | 3.0 | 0.00 | 2.0 | 0.00 | 3.0 | 0.00 | 5.0 | 0.00 | 1.0 | 0.00 | 1.0 | 0.00 | 3.0 | 0.00 |

By Frequency of Use

| | | % of | Method of Use | | Value | | Knowledge | | 32 Criteria | | Criteria Implementation | | Usefulness | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Respondents | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. |
| Less than Once / wk | 16 | 64% | 2.4 | 1.0 | 2.5 | 1.2 | 3.2 | 0.9 | 1.8 | 0.4 | 1.0 | 0.0 | 2.8 | 0.9 |
| More than Once / wk | 9 | 36% | 3.0 | 0.5 | 3.6 | 0.7 | 3.4 | 0.7 | 1.7 | 0.5 | 1.0 | 0.0 | 3.6 | 0.7 |

By Method of Use

| | | % of | Frequency | | Value | | Knowledge | | 32 Criteria | | Criteria Implementation | | Usefulness | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Respondents | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. |
| Report Only | 2 | 8% | 2.0 | 0.00 | 1.5 | 0.71 | 3.0 | 0.00 | 2.0 | 0.00 | #DIV/0! | #DIV/0! | 2.5 | 0.71 |
| Report & Some Manage | 9 | 36% | 2.8 | 0.7 | 2.6 | 1.1 | 3.1 | 1.1 | 1.9 | 0.3 | 1.0 | #DIV/0! | 2.8 | 0.8 |
| Report/Manage | 8 | 32% | 3.9 | 1.0 | 3.8 | 0.7 | 3.5 | 0.8 | 1.6 | 0.5 | 1.0 | 0.0 | 3.6 | 0.7 |
| Manage & Some Report | 4 | 16% | 2.8 | 1.0 | 2.5 | 1.3 | 3.8 | 0.5 | 1.5 | 0.6 | 1.0 | 0.0 | 3.0 | 1.2 |
| Manage Only | 0 | 0% | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

By Value

| | | % of | Frequency | | Method of Use | | Knowledge | | 32 Criteria | | Criteria Implementation | | Usefulness | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Respondents | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. |
| Average or below | 17 | 68% | 2.9 | 1.0 | 2.5 | 1.0 | 3.3 | 0.9 | 1.8 | 0.4 | 1.0 | 0.0 | 2.6 | 0.6 |
| Above Average | 8 | 32% | 3.5 | 0.9 | 2.9 | 0.6 | 3.3 | 0.7 | 1.6 | 0.5 | 1.0 | 0.0 | 4.0 | 0.5 |

By Knowledge

| | | % of | Frequency | | Method of Use | | Value | | 32 Criteria | | Criteria Implementation | | Usefulness | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Respondents | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. |
| Average or below | 14 | 56% | 2.9 | 0.9 | 2.3 | 0.9 | 2.9 | 1.3 | 1.9 | 0.4 | 1.0 | 0.0 | 3.1 | 0.9 |
| Above Average | 11 | 44% | 3.4 | 1.1 | 3.0 | 0.8 | 2.8 | 1.0 | 1.6 | 0.5 | 1.0 | 0.0 | 2.9 | 0.8 |

By 32 Criteria

| | | % of | Frequency | | Method of Use | | Value | | Knowledge | | Criteria Implementation | | Usefulness | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Respondents | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. |
| Yes | 6 | 24% | 3.3 | 0.8 | 3.2 | 0.8 | 3.7 | 0.8 | 3.8 | 0.8 | 1.0 | 0.0 | 3.8 | 0.8 |
| No | 19 | 76% | 3.0 | 1.1 | 2.4 | 0.9 | 2.6 | 1.1 | 3.1 | 0.8 | #DIV/0! | #DIV/0! | 2.8 | 0.8 |

By Usefulness

| | | % of | Frequency | | Method of Use | | Value | | Knowledge | | 32 Criteria | | Criteria Implementation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number | Respondents | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. | μ | S.D. |
| Average or below | 17 | 68% | 2.9 | 1.1 | 2.4 | 0.9 | 2.4 | 0.9 | 3.3 | 0.9 | 1.9 | 0.3 | 1.0 | 0.0 |
| Above Average | 8 | 32% | 3.4 | 0.7 | 3.0 | 0.8 | 4.0 | 0.5 | 3.3 | 0.7 | 1.5 | 0.5 | 1.0 | 0.0 |

Proposition Tests *One-sided, Two-sample T-test*

| | $P_o$: Higher knowledge results in higher value | $P_o$: Higher usefulness results in more management use | $P_o$: Higher value results in higher frequency |
|---|---|---|---|
| observed difference = | -0.1 | 0.6 | 0.6 |
| $\alpha$ = | 0.1 | 0.1 | 0.1 |
| d.f. = | 23 | 23 | 23 |
| tdist = | 1.31946024 | 1.31946024 | 1.31946024 |
| $s_p$ = | 1.152783683 | 0.866204687 | 0.972775185 |
| Rejection Region = | 0.61284941 | 0.490024041 | 0.550312454 |
| Conclusion = | Reject Po | Fail to Reject Po | Fail to Reject Po |

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